THE POTENTIAL FOR ACCIDENT REDUCTION BY IMPROVING URBAN SKID RESISTANCE LEVELS

by

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A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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1985

ABSTRACT

The problem of providing adequate wet-road skid resistance on urban roads has received relatively little attention from highway maintenance authorities. This study is an assessment of the potential for reducing accident rates by improving skid resistance levels on such roads. Reasons for the neglect of urban skid resistance are discussed and an assessment made of the scale of the skidding problem in this context. Evidence is presented to demonstrate that the potential for accident reduction is greater than is indicated by the statistics for reported skidding accidents. The pattern of frictional demand and the measurement of skid resistance are discussed, as are the technical difficulties associated with maintaining good skid resistance on heavily-trafficked roads. The performance of conventional surfacing materials is assessed and recently-developed materials are evaluated. It is suggested that the attainment of high skid resistance is inhibited by economic rather than technical factors. Nationally-proposed standards for skid resistance are examined and modifications are suggested for urban use. The problem of defining accident risk at an individual site is examined and the relationship between accident rate and skid resistance investigated using regression techniques with data from the Greater London area. Criteria are developed for identifying sites where an improvement in skid resistance is likely to be effective in reducing accidents and consideration is given to the economic justification for skid resistance improvements. Alternative strategies are considered and a policy is proposed which would be practicable and cost-effective and, it is argued, could lead to a substantial reduction in accident rates.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

AAV - aggregate abrasion value
ATS - automatic traffic signals
BFC - braking force coefficient
DTp - Department of Transport
GLC - Greater London Council
HRA - hot-rolled asphalt
NPV - net present value
PMV - polished mortar value
PSV - polished stone value
PVB - present value of benefits
PVC - present value of costs
QMC - Queen Mary College, University of London
RRL - Road Research Laboratory
SFC - sideway-force coefficient (measured at 50 km/h)
TRRL - Transport and Road Research Laboratory
s.e. - standard error
cvd - commercial vehicles per day
tau - Kendall rank correlation coefficient

Note: Abbreviated variable names are defined within the text and are also listed in the Appendices.

SYMBOLS

a - acceleration
F - limiting frictional force
g - gravitational constant
k - repeatability
K - reproducibility
p - polished stone value
r - correlation coefficient
t - traffic flow
v - velocity
V - variance
μ - coefficient of friction

ACKNOWLEDGEMENTS

Thanks are offered to my supervisor, Dr. David Powell, of Queen Mary College for valuable advice and guidance. Also to Leslie Hatherly, formerly of the Greater London Council, for advice and encouragement, and for initiating the GLC work on skid resistance improvement, without which this study would not have been possible. I am indebted to GLC colleagues William Davidson, Hugh Davidson, Ted Young and Roy Ritchie for assistance at various stages of the work, to John Brownfield, Jim Landles and Eric Chinn for help with accident data and to Ricky Ye'Myint for advice on computing. I am grateful to Roger Hosking of the Transport and Road Research Laboratory, Tom Gargett of the Department of Transport, Chris Garrett of Kent County Council, Len Parker of Surrey County Council and Ray Forrester of West Yorkshire County Council for useful discussions on many aspects of the study. I must specially thank Heather, my wife, for putting up with all the lost weekends.

I am grateful to the Greater London Council for permission to use GLC data. The opinions expressed are, of course, my own and not necessarily those of the GLC.

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

In Great Britain road accident rates are low compared with rates in most other countries (1)*. Road safety has always been recognised as being of great social and economic importance and successive Governments have actively supported measures to reduce the accident toll. Road safety research, legislation, enforcement activities, education and information programmes, road improvements, traffic management schemes and improved vehicle design have all helped to moderate the accident rates. However, there is still considerable potential for accident reduction. It has been estimated (2) that injury accidents could be reduced by 60% by the application of existing knowledge relating to road engineering, vehicle design and road user behaviour.

The road accidents which occurred in Great Britain in 1980 were estimated (3) to have cost the community £2,000,000,000. This represents a considerable drain on national resources (quite apart from an immense amount of grief and suffering) and it is, therefore, important to identify and implement those measures which are most effective in reducing accident rates. In the present economic climate, with severe restrictions on public expenditure, it is necessary to ensure that the most effective use is made of the limited funds which are available for road maintenance and road safety purposes. The Institution of Highway Engineers' publication "Guidelines for Accident Reduction and Prevention in Highway Engineering" (3) emphasises the fact that low-cost engineering measures can provide particularly good value for money. One such measure - the improvement of road surface skid resistance in urban areas - is the subject of this study.

The problem of skidding on wet roads has been a major highway engineering research topic for many years in Great Britain (4). The work at the Transport and Road Research Laboratory (TRRL) and elsewhere has led to a better understanding of the tyre/road interface, road surfacing materials, vehicle frictional demand and the relationship between skid resistance and accident risk. This has resulted in better tyres, improved road surfacing specifications and

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* NOTE * references are listed on page 285

the formulation of target minimum skid resistance values. Even so, the wet-road skidding rate remains high. Skidding was reported in 28% of accidents occurring on wet roads in 1980, compared with 14% on dry roads (5). There is clearly considerable scope for accident reduction by improving wet-road skid resistance.

Skidding is often thought of as a problem which is confined mainly to rural roads, where vehicle speeds are relatively high. The accident statistics indicate that the wet-road skidding rate on urban roads (i.e. roads in built-up areas) is only half that on rural roads (6). Possibly as a consequence of this, much of the research work has been directed at rural roads. This is unfortunate because the rural skidding problem is somewhat different from that in urban areas and the rural research findings are not necessarily applicable to urban roads. Another consequence is that (with a few notable exceptions) the highway maintenance authorities have paid scant attention to skid resistance on urban roads and very little money has been allocated for urban skid resistance improvements. There is a clear need for an assessment of the potential for accident reduction by the improvement of skid resistance levels on urban roads and for the formulation of a rational policy for urban skid resistance.

1.2 NEGLECT OF URBAN SKID RESISTANCE - PAST AND PRESENT

Before attempting to formulate a policy on urban skid resistance it is worth examining the reasons why it has been somewhat neglected by highway authorities and by individual highway engineers. They arise from a combination of human, administrative, economic, technical and legal factors. Some of them apply also to rural areas and some no longer apply but their effects are still in evidence.

A vehicle will skid when, in manoeuvring, braking or accelerating, the frictional demand is greater than the tyre/road interface can generate. This situation can arise through misjudgement - such as when a driver attempts to negotiate a bend at too high a speed- or when emergency braking is necessary - such as when a vehicle ahead stops suddenly or a pedestrian steps into the road unexpectedly.

Some highway engineers take the view that most skids are the consequence of bad driving. They are unsympathetic to the suggestion that they should spend money on improving skid resistance levels when the fault lies with the driver. They argue that skidding accidents could be prevented - at zero cost - if drivers simply exercised more care. They do, of course, accept that it is their responsibility to deal with areas which have become unduly slippery because of a surfacing failure (e.g. fatted-up surface dressing) or surface contamination, because the skid resistance is then lower than the driver could reasonably expect to encounter. It may well be true that most skidding accidents are due to driver error, and that if drivers exercised better judgement and were more observant then the need for harsh braking and manoeuvring would be reduced. Unfortunately, experience has shown that it is very difficult to improve driver behaviour to any great extent. Engineers must accept the fact that expenditure on engineering measures is often necessary in order to offset driver inadequacies.

The published accident statistics show that the wet-road skidding rate on urban roads is only half that on rural roads. As a consequence highway authorities allocate most of the money which is available for skid resistance improvements to the rural parts of their network where the skidding problem is apparently more acute. However, the wet-road skidding rate (the percentage of wet-road accidents in which skidding is reported) is not necessarily the best parameter for use in deciding where to allocate resources to achieve the greatest reduction in accidents. It is sometimes more appropriate to consider actual numbers of skidding accidents. As will be demonstrated in Chapter 2, the majority of skidding accidents occur on urban roads. There is, therefore, a strong case for devoting at least as much attention to urban roads as to rural ones.

There is a natural tendency for highway authorities to compare their wet-road skidding rate with the national average. This has led to complacency amongst those authorities whose network is predominantly urban, such as the Metropolitan counties or the old county boroughs. They have often assumed that because their skidding rate is well below average their general standard of skid resistance is satisfactory and there is little scope for accident reduction by improving skid resistance levels.

Some highway authorities have simply been unaware of the extent of the skidding problem in their area because they have not had access to detailed accident records. Police accident reports are confidential documents and the highway authority does not have a statutory right of access to them. The release of their contents is at the discretion of the local Chief Constable. The extent to which the police analyse the accident records and pass on either their findings or the actual accident details varies considerably between different areas. Chief Constables have occasionally been reluctant to make some of the information on the accident reports available to highway authorities - particularly the smaller authorities - partly because of the additional demands on police manpower and partly because the information is not always put to good use. An underlying factor which has inhibited co-operation between the police and the highway authorities is the fact that police officers tend to be more concerned with apportioning blame for an accident than with asking themselves how the accident could have been prevented. Although skidding accidents are frequent, low skid resistance is very rarely recorded as being a contributory factor. In any case, there is a widespread belief amongst police officers that skidding accidents are due solely to bad driving. Consequently, even when they have identified a major skidding accident blackspot they will not necessarily ask the highway authority to take action to improve the skid resistance. Engineers sometimes learn of a skidding accident site only through complaints from local residents. Even when an authority has had full access to police accident records it has not always carried out the sort of systematic studies which would highlight localities with an above-average wet-road skidding rate. The emphasis has often been on providing routine statistics on casualties for the benefit of the local politicians and road safety officers, with a view to planning road safety campaigns rather than engineering measures to reduce accidents.

Within a highway authority, liason is often poor between the traffic engineers, who are responsible for accident analysis, and the maintenance engineers who are in a position to implement skid resistance improvements. Consequently, maintenance engineers are often unaware of high skidding accident rates, either generally or at specific sites, and traffic engineers are unaware of what improvements in skid resistance are feasible.

Until recently most engineers had no means of monitoring the skid resistance of their network and excessively slippery areas came to light only as a result of skidding accidents. The TRRL portable skid resistance tester (described in Chapter 3) has been available for many years but is not suitable for large-scale testing programmes. Many of the smaller urban highway authorities which existed until recently had very limited technical resources and did not have a highways laboratory for testing surfacing materials or carrying out skid resistance tests.

The Highways Act, 1980 requires each highway authority to maintain its roads in a safe condition. This implies that an adequate level of skid resistance should be provided but there is no legal definition of 'adequate' and there are no mandatory standards for minimum skid resistance. The various standards which have been proposed are discussed in Section 1.3 and in Chapter 5. They have only advisory status and are considered by some authorities to be unrealistic for urban roads, particularly at high-stress locations on main roads, where it is often impossible to maintain the proposed levels of skid resistance with conventional surfacing materials. Certain authorities have deliberately refrained from carrying out routine skid resistance tests on their roads. They have been told by their legal advisers that, in the event of a claim against the authority following a skidding accident at a site which is very slippery, they would be less culpable if they were ignorant of the state of the road than if they were aware that it was very slippery but had taken no action to improve the skid resistance. This policy may help the authority in defending legal actions brought by unfortunate road users but it is morally questionable. In the United States a series of court decisions (7) has established that the highway authority has a duty to improve the skid resistance at known skidding hazard sites and, furthermore, that it must exercise reasonable diligence in identifying such sites (i.e. by systematic measurement of skid resistance and/or by accident studies). It is accepted that it is unreasonable to expect the authority to deal immediately with all identified hazard sites and that the decision on which sites to correct first is discretionary. The rate at which the hazard sites are improved will depend upon the funds available for this purpose. Some authorities might consider that provided they do have a skid resistance improvement programme it needs only to be a token one to ensure that they are safeguarded legally.

The perpetual problem in highway maintenance is the shortage of funds. Even when the need for specific skid resistance improvements has been established there are often insufficient funds available to fully implement the required improvements. Most of the money available for highway maintenance must be used for those activities which the highway authority has a statutory obligation to perform. The amount available for road surfacing improvements is very limited and the maintenance engineer usually has to concentrate on maintaining the structural integrity of the road rather than on enhancing skid resistance.

It is technically difficult to achieve and maintain good skid resistance on heavily trafficked urban roads. The areas where it is most difficult are those where traffic is braking or turning. These are, of course, areas where frictional demand is high and good skid resistance is particularly important. Unit costs for resurfacing are higher in urban areas because of the difficult operating conditions, traffic problems, restrictions on daytime working and the generally smaller areas involved. Costs are also higher because on urban main roads it is rarely possible to use some of the cheaper processes (e.g. conventional surface dressing) which are widely used on rural roads. Because of the difficult operating conditions in urban areas the standards of workmanship and the quality of the surfacing materials are often relatively poor, particularly where the highway authority does not have laboratory facilities or properly-trained staff to supervise the work on site. Consequently, the durability and the skid resistance of road surfaces on urban roads are generally lower than for the equivalent materials on rural roads.

In addition to improving skid resistance at specific sites with a history of skidding accidents there is also considerable scope for accident reduction by raising the general level of skid resistance throughout a network. This could be achieved at a relatively modest cost by selecting roadstones which are more polish-resistant. Certain authorities appear to have been more concerned with the aesthetic appearance of the road than with skid resistance and have selected their roadstones on the basis of colour rather than polish-resistance.

Others have insisted that only local aggregates should be used, even when they are demonstrably of inferior quality.

1.3 RECENT DEVELOPMENTS

In recent years there have been many important developments which could contribute to a reduction in urban skidding accidents. They include :-

1. The reorganisation of local government in Great Britain, which substantially reduced the number of highway authorities.

2. The Road Traffic Act, 1974 which imposed a statutory duty on local authorities to promote road safety.

3. The computerisation of accident records.

4. The introduction of the SCRIM road testing vehicle with which it is possible to monitor the skid resistance of an entire road network.

5. The publication of TRRL report LR 504 by Szatkowski and Hosking (8) in which it is demonstrated that the skid resistance of a conventional road surfacing can be predicted from a knowledge of the traffic flow and the roadstone properties.

6. The development of new surfacing materials giving improved skid resistance.

7. The publication of TRRL report LR 510 by Salt and Szatkowski (9) in which a new system of skid resistance standards is proposed.

8. The Greater London Council skid resistance improvement programme.

The reorganisation of local government in England and Wales was brought about by the Local Government Act, 1972 which was implemented in 1974. The new county councils (plus the GLC and the London boroughs) became the highway authorities for all classified non-trunk roads. Under similar legislation for Scotland the new councils for the regions and islands became the highway authorities. This reduced the number of highway authorities from 1192 to 98. The large authorities thus created had greater resources at their disposal and were able to recruit specialist staff for road safety investigations. The Department of Transport (DTp), The Welsh Office and the Scottish Development Department remained highway authorities for all trunk roads.

Section 8 of the Road Traffic Act, 1974 declared that the new highway authorities should

> "prepare and carry out a programme of measures designed to promote road safety, and shall have power to make contributions to the cost of measures for promoting road safety taken by other authorities or bodies".

The measures referred to included the carrying out of accident studies and the implementation of traffic management, road construction, improvement and maintenance schemes to reduce accidents. The Act gave considerable impetus to the implementation of engineering measures to reduce accidents. Most highway authorities have allocated funds for accident remedial measures either as a special allocation or from the traffic management or road maintenance budgets. They have set up teams of engineers and technicians to analyse accident data, identify accident blackspots and formulate a programme of remedial measures. Where there is a cluster of wet-road skidding accidents the recommended action is, of course, an improvement in skid resistance. Thus, accident rates have been reduced at a number of sites by improving the skid resistance. In the main these have been the major skidding blackspot sites, which are relatively few in number, particularly in urban areas. Very few authorities appear to have assessed the potential for accident savings by widespread skid resistance improvements. Even fewer appear to have realised the potential on the urban sections of their network. Consequently, although the administrative and financial structure for road safety engineering measures has greatly improved and many schemes have been implemented, there is little additional expenditure on skid resistance improvements on urban roads.

A key factor in the analysis of accidents and the study of relationships between various accident, traffic and road parameters is the ready access to the accident records. In order to obtain details of accidents at particular sites it was necessary until recently to work manually through police files to locate individual accident reports. Most police forces have computerised their accident records and the coded data from the standard accident reporting form can be accessed rapidly. The release of accident records is still at the discretion of the police but now that there are far fewer highway authorities there is much closer liaison between them and the police.

The SCRIM test vehicle was designed at the TRRL. It measures the Sideway Force Coefficient, SFC (defined in Chapter 3) which is a measure of the coefficient of friction between a standard test tyre and the wet road surface. SCRIM is the first machine to be available to local authorities for large-scale routine testing of skid resistance. It makes it possible for a highway authority to locate areas within its road network which are relatively slippery or to compare the skid resistance of a section of road with a predetermined target value. It also provides a means of monitoring the performance of different surfacing materials. The machine is described in Chapter 3. In Great Britain four machines are owned by local authorities, three by the TRRL and one by the Department of Transport. In addition, two are owned by the manufacturers, WDM Ltd of Bristol, who provide a testing service for highway authorities. Many authorities have now used SCRIM but have tended to restrict their testing to the rural classified roads, largely ignoring the urban main roads because they are more difficult to test and have lower skidding rates. The only authorities who are now unaware of the state of the skid resistance of their network are those who choose to remain so.

Road surfaces become slippery mainly as a result of the polishing action of vehicle tyres. In the past it was thought that the polishing effect was cumulative and that the skid resistance of any section of road would gradually fall from year to year. It was known that certain stone types were more resistant to polishing than others and an accelerated polishing test, known as the Polished Stone Value (PSV) Test (10) was devised by the TRRL to assess the relative polish resistance of various roadstones. Szatkowski and Hosking investigated the long-term skid resistance performance of conventional road surfacings (hot-rolled asphalt and surface dressing) and found that, for constant traffic flow, the skid resistance did not steadily decrease from year to year but fell fairly rapidly (within about one year) to an equilibrium level which depended on the traffic flow and on the PSV of the aggregate at the surface. They were able to define a general relationship between skid resistance, PSV and traffic flow.

$$S = 2.4 \times 10^{-2} - 6.63\ t \times 10^{-5} + p \times 10^{-2} \qquad \underline{\text{Eq. A}}$$

where s = equilibrium mean summer SFC measured at 50 km/h
t = flow of commercial vehicles per lane per day (cvd)
p = aggregate polished stone value (PSV)

This was an important finding, for it meant that it was now possible to define the aggregate PSV required at a particular site to achieve the target SFC. Szatkowski and Hosking's findings were published in TRRL Report LR 504 (8) in 1972 and were incorporated into the Department of Transport specification for new roads (11) in 1976.

There are indications that in urban areas present SFC levels are somewhat lower on average than would be predicted by equation A. Possible reasons for this are discussed in Chapter 4 where an investigation into the SFC performance of hot-rolled asphalt on main roads in London is described.

As well as providing a rational basis for the selection of roadstones, Szatkowski and Hosking's work also defines the SFC limits attainable with natural aggregates in conventional surfacing materials. It is evident from equation A that, even with the highest PSV stones found in this country, only a moderate SFC can be maintained with conventional surfacing materials on heavily-trafficked roads. Equation A is valid only for rolling traffic. The equilibrium SFC is lower at high-stress sites such as approaches to traffic signals, roundabouts and pedestrian crossings (42). These are, of course, areas where good skid resistance is most important. This limitation of conventional materials has prompted work on the development of other materials which can give a better SFC performance on urban roads. The more important of these are described in Chapter 4 and an assessment made of their performance. Their development means that materials are now available which make it possible to achieve high levels of skid resistance at even the most highly-stressed locations.

With the range of surfacing materials available and the knowledge of their performance it is now possible to select the appropriate surfacing material to achieve the required target SFC at an individual location. The selection of appropriate target SFC levels remains a problem. In Great Britain there are no mandatory minimum SFC levels. A number of suggested standards of SFC have been proposed but none has been generally adopted. The more important of the suggested standards, emanating from Giles (12), The Marshall Committee (13) and Salt and Szatkowski (9), are discussed in detail in Chapter 5. Giles's proposals (12) resulted from an extensive study in which he looked at vehicle performance, at vehicle frictional demand at various sites, at relative accident risk in relation to SFC, and at the levels of SFC which were then attainable. His proposals were to some extent a compromise between what he felt was desirable and what was achievable. His observations were made in the early 1950's mainly on rural roads. The findings are not necessarily valid for urban roads or for present-day traffic conditions and yet they were accepted by the Marshall Committee in 1970 and were used as the basis for the Salt and Szatkowski proposals published in LR 510. The latter work introduced the very useful concept of 'risk rating'; the target SFC value for a particular site depending upon the relative risk of a skidding accident at that site. In practice it can be extremely difficult to define reliable risk ratings and Chapter 6 gives further consideration to this problem.

Salt and Szatkowski's proposals have been incorporated into the DTp specification for new roads. For legal reasons the specification avoids stating minimum SFC values but uses risk ratings to specify minimum PSV requirements. The DTp specification relates only to Motorways and Trunk roads but is often applied by highway authorities to other classes of road.

The implementation of the proposals in LR 510 and the findings described in LR 504 are undoubtedly leading to improvements in surfacing materials by directing attention to those areas where a higher SFC level is necessary and by giving guidance on how to achieve the target SFC levels. In urban areas it can cost a great deal of money to achieve the LR 510 standards and consideration must be given to whether the expenditure can be justified. The main benefit resulting from an increase in skid resistance is, of course, a reduction in the number of accidents. The monetary value which can be assigned to accidents thus prevented provides a basis for carrying out a cost-benefit assessment of a skid resistance improvement programme. The 'cost' part of the exercise is relatively straightforward in principle. It involves measuring SFC levels throughout the road network and estimating the cost of improving the surfacing in areas where the SFC is considered to be deficient. The benefits in terms of reduced accident costs are very much more difficult to assess and no-one has yet done this satisfactorily. To do so it is necessary to define the relationship between skid resistance and accident rate. There are two ways in which this can be done. Firstly, by correlating SFC and accidents at a large number of sites and hence obtaining regression equations. Secondly, by observing changes in accident rate following changes in SFC levels at experimental sites. Both methods are used in this study and are described in Chapter 7.

From the road user's point of view the target SFC should be the highest technically attainable. Consideration is given to this approach in Chapter 8 and, on the basis of the findings in Chapter 7, an estimate is made of the potential saving in accidents which would result from the attainment of the highest possible SFC levels on the urban classified roads. From a purely economic standpoint expenditure on improving skid resistance can be justified only if the saving in accident costs exceeds the cost of the skid resistance improvements. In Chapter 9 an estimate is made of the expenditure required and is compared with the accident savings. Consideration is given to secondary costs and benefits which might arise. In Chapter 8 methods of identifying sites where a skid resistance improvement is most likely to produce a reduction in accidents are examined.

In Chapter 9 consideration is given to the SFC levels on main roads in a typical London borough and an assessment is made of the extent to which they are deficient in relation to LR 510. The cost of achieving compliance is estimated and an assessment is made of the net economic benefits resulting from compliance. The target SFC values proposed in LR 510 are somewhat arbitrary and although a net benefit may result from their attainment this would not necessarily represent the best use of maintenance funds. Alternative strategies are examined in order to formulate a policy for improving skid resistance to achieve maximum accident savings cost-effectively.

The GLC skid resistance improvement programme which was started in 1967 has provided much of the data for this study. It is of particular importance because it has demonstrated that by improving skid resistance levels substantial reductions in accident rates can be achieved even in an area where the reported wet-road skidding rate is already very low.

1.4 OBJECTIVES

The overall objective of the study is to define a cost-effective strategy for reducing accident rates by improving skid resistance on urban roads.

Detailed objectives are to :-

1. Estimate the potential saving in accidents which could be achieved in urban areas by improving skid resistance.
2. Assess the skid resistance performance of conventional surfacing materials currently in use on urban roads.
3. Assess the performance of new surfacing materials.
4. Consider the extent to which the proposed national standards for skid resistance are appropriate for urban roads.
5. Examine the problem of defining accident risk at an individual site.
6. Investigate the relationship between skid resistance and accident rate in urban areas.
7. Consider the economic justification for urban skid resistance improvements.
8. Examine alternative skid resistance improvement strategies and hence define a strategy for the effective use of maintenance funds to reduce wet-road accidents.

CHAPTER 2

ACCIDENTS

2.1 ACCIDENT RECORDS

In Great Britain there is no general requirement for road accidents to be reported to the police. The Road Traffic Act, 1972, simply requires that the driver of a motor vehicle involved in an accident should give to any interested party details of himself, his vehicle and, if someone is injured, his insurance. Only if the driver does not do this is he required to report the accident to the police. Consequently, many injury accidents are not reported. A TRRL study (14) revealed that 30% of the road accident casualties attending a large accident hospital in Berkshire were not reported to the police.

Details of the injury accidents which are reported to the police are recorded on a standard Department of Transport (DTp) form known as Stats 19, the current version of which is shown in Fig. 2.1. It has provision for recording in a standard manner details of the location, time, casualties, vehicles, drivers, road surface conditions, weather conditions, vehicle manoeuvres, occurrence of skidding and other relevant factors. The procedures for recording damage-only accidents vary considerably between different areas and hence the reports are of limited value for statistical purposes. It has been estimated (15) that for every injury accident there are, on average, about six damage-only ones.

The Stats 19 form requires 17 items of information for each casualty, 25 for each vehicle and 27 for the attendant circumstances. Inevitably, the information will sometimes be incomplete, particularly where, as happens in about a third of the reported injury accidents, the police have not attended the scene of the accident. The driver reporting the accident may not have details of other drivers, vehicles and casualties involved and may also be vague about the location. The extent to which the police will attempt to fill the information gaps will depend upon the severity of the accident and whether a prosecution is involved. Clearly, a fatal accident will merit more police time than one involving only slight injury.

ACCIDENT RECORD ATTENDANT CIRCUMSTANCES

1·1 RECORD TYPE [1 2: 1_]
1 New accident record
5 Amended accident record

1·2 POLICE FORCE [3 4]

1·3 ACCIDENT REF NO [5 6 7 8 9 10 11]

1·4 SEVERITY OF ACCIDENT [12]
1 Fatal 2 Serious 3 Slight

1·5 NUMBER OF VEHICLES [13 14 15]

1·6 NUMBER OF CASUALTY RECORDS [16 17 18]

1·7 DATE [Day 19 20 | Month 21 22 | Year 23 24]

1·8 DAY OF WEEK [25]
1 Sunday 2 Monday
3 Tuesday 4 Wednesday
5 Thursday 6 Friday
7 Saturday

1·9 TIME [Hrs 26 27 | Mins 28 29]
24 hour

1·10 LOCAL AUTHORITY [30 31 32]

1·11 LOCATION [Easting 33 | 34 35 36 37] [Northing 38 | 39 40 41 42]
10 digit reference No

1·12 1st ROAD CLASS [43]
1 Motorway
2 A (M)
3 A
4 B
5 C
6 Unclassified

1·13 1st ROAD NUMBER [44 45 46 47]

1·14 CARRIAGEWAY TYPE OR MARKINGS [48]
1 Roundabout (on circular highway)
2 One way Street
3 Dual carriageway - 2 lanes
4 Dual carriageway - 3 or more lanes
5 Single carriageway - single track road
6 Single carriageway - 2 lanes (one each direction)
7 Single carriageway - 3 lanes (two way capacity)
8 Single carriageway - 4 or more lanes (two way capacity)
9 Unknown

1·15 SPEED LIMIT [49 50 51: 0_ _]
mph

JUNCTION ACCIDENTS ONLY

1·16 JUNCTION DETAIL [52 53: 0_]
0 Not at or within 20 metres of junction
1 Roundabout
2 Mini - roundabout
3 'T' or staggered junction
4 'Y' junction
5 Slip road
6 Crossroads

1·17 JUNCTION CONTROL [54]
1 Authorised person
2 Automatic traffic signal
3 Stop sign
4 Give way sign or markings
5 Uncontrolled

1·18 2nd ROAD CLASS [55]
1 Motorway
2 A (M)
3 A
4 B
5 C
6 Unclassified

1·19 2nd ROAD NUMBER [56 57 58 59]

1·20 PEDESTRIAN CROSSING FACILITIES [60 61: 0_]
0 No crossing facilities within 50 metres
1 Zebra
2 Zebra crossing controlled by school crossing patrol
3 Zebra crossing controlled by other authorised person
4 Pelican
5 Other light controlled crossing
6 Other sites controlled by school crossing patrol
7 Other sites controlled by other authorised person
8 Central refuge - no other controls
9 Footbridge or subway

1·21 LIGHT CONDITIONS [62]
DAYLIGHT
1 Street lights 7 metres or more high
2 Street lights under 7 metres high
3 No street lighting
4 Daylight street lighting unknown
DARKNESS
5 Street lights 7 metres or more high lit
6 Street lights under 7 metres high lit
7 No street lighting
8 Street lights unlit
9 Darkness street lighting unknown

1·22 WEATHER [63]
1 Fine (without high winds)
2 Raining (without high winds)
3 Snowing (without high winds)
4 Fine with high winds
5 Raining with high winds
6 Snowing with high winds
7 Fog (or mist if hazard)
8 Other
9 Unknown

1·23 ROAD SURFACE CONDITION [64]
1 Dry
2 Wet / Damp
3 Snow
4 Frost / Ice
5 Flood (surface water over 3 cms (1 inch) deep)

1·24 SPECIAL CONDITIONS AT SITE [65]
0 None
1 Automatic Traffic Signal - out
2 Automatic Traffic Signal partially defective
3 Permanent road signing defective or obscured
4 Road works present
5 Road surface defective

1·25 CARRIAGEWAY HAZARDS [66]
0 None
1 Dislodged vehicle load in carriageway
2 Other object in carriageway
3 Involvement with previous accident
4 Dog in carriageway
5 Other animal in carriageway

1·26 OVERTAKING MANOEUVRE PATTERNS [67]
NO LONGER REQUIRED BY DTp STATISTICS

1·27 DTp SPECIAL PROJECTS [68 69 70 71]

Stats 19 (Rev May 1982)

FIG. 2.1A Stats 19 accident reporting form - attendant circumstances section

Department of Transport

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VEHICLE RECORD

2.1 RECORD TYPE [2] (1 2)
1 New vehicle record
5 Amended vehicle record

2.2 POLICE FORCE (3 4)

2.3 ACCIDENT REF NO (5 6 7 8 9 10 11)

2.4 VEHICLE REF NO (12 13 14)

2.5 TYPE OF VEHICLE (15 16)
01 Pedal cycle
02 Moped
03 Motor scooter
04 Motor cycle
05 Combination
06 Invalid Tricycle
07 Other three-wheeled car
08 Taxi
09 Car (Four wheeled)
10 Minibus/Motor
11 P S V
12 Goods not over 1½ tons UW (1·52 tonnes)
13 Goods over 1½ tons UW (1·52 tonnes)
14 Other motor vehicle
15 Other non motor vehicle

2.6 TOWING AND ARTICULATION (17)
0 No tow/articulation
1 Articulated vehicle
2 Double/multiple trailer
3 Caravan
4 Single trailer
5 Other tow

2.7 MANOEUVRES (18 19)
01 Reversing
02 Parked
03 Waiting to go ahead but held up
04 Stopping
05 Starting
06 U Turn
07 Turning left
08 Waiting to turn left
09 Turning right
10 Waiting to turn right
11 Changing lane to left
12 Changing lane to right
13 Overtaking moving vehicle on its offside
14 Overtaking stationary vehicle on its offside
15 Overtaking on nearside
16 Going ahead left hand bend
17 Going ahead right hand bend
18 Going ahead other

2.8 VEHICLE MOVEMENT COMPASS POINT (20 21) From To
1 N
2 NE
3 E
4 SE
5 S
6 SW
7 W
8 NW
or [0 0] Parked - not at kerb
[0] Parked - at kerb

2.9 VEHICLE LOCATION AT TIME OF ACCIDENT (22 23)
01 Leaving the main road
02 Entering the main road
03 On main road
04 On minor road
05 On service road
06 On lay-by or hard shoulder
07 Entering lay-by or hard shoulder
08 Leaving lay-by or hard shoulder
09 On a cycleway
10 Not on carriageway

2.10 JUNCTION LOCATION OF VEHICLE AT FIRST IMPACT (24)
0 Not at junction (or within 20 metres/22 yards)
1 Vehicle approaching junction vehicle parked at junction approach
2 Vehicle in middle of junction
3 Vehicle cleared junction/vehicle parked at junction exit
4 Did not impact

2.11 SKIDDING AND OVERTURNING (25)
0 No skidding-jackknifing or overturning
1 Skidding
2 Skidded and overturned
3 Jacknifed
4 Jacknifed and overturned
5 Overturned

2.12 HIT OBJECT IN CARRIAGEWAY (26 27)
00 None
01 Previous accident
02 Road works
03 Parked vehicle-lit
04 Parked vehicle-unlit
05 Bridge(roof)
06 Bridge(side)
07 Bollard/refuge
08 Open door of vehicle
09 Central island of roundabout
10 Kerb
11 Other object

2.13 VEHICLE LEAVING CARRIAGEWAY (28)
0 Did not leave carriageway
1 Left carriageway nearside
2 Left carriageway nearside and rebounded
3 Left carriageway straight ahead at junction
4 Left carriageway offside onto central reservation
5 Left carriageway offside onto central reservation and rebounded
6 Left carriageway offside crossed central reservation
7 Left carriageway offside
8 Left carriageway offside and rebounded

2.14 HIT OBJECT OFF CARRIAGEWAY (29 30)
00 None
01 Road sign/Traffic signal
02 Lamp post
03 Telegraph pole/Electricity pole
04 Tree
05 Bus stop/Bus shelter
06 Central crash barrier
07 Nearside or offside crash barrier
08 Submerged in water (completely)
09 Entered ditch
10 Other permanent object

2.15 VEHICLE PREFIX/ SUFFIX LETTER (31)
PREFIX/SUFFIX LETTER or one of the following codes:-
0 Pre 1963
1 Unknown/cherished number/not applicable
2 Foreign/diplomatic
3 Military
4 Trade Plates

2.16 FIRST POINT OF IMPACT (32)
0 Did not impact
1 Front
2 Back
3 Offside
4 Nearside

2.17 OTHER VEHICLE HIT (VEH REF NO) (33 34 35)

2.18 PART(S) DAMAGED (36 37 38)
0 None
1 Front
2 Back
3 Offside
4 Nearside
5 Roof
6 Underside
7 All four sides

2.19 NO OF AXLES (39)
0 Not goods vehicle
2 2 axles
3 3 axles
4 4 axles
5 5 or more axles
(Goods Vehicles only)

2.20 MAXIMUM PERMISSIBLE GROSS WEIGHT (40 41)
Metric tonnes (Goods vehicle only)

2.21 SEX OF DRIVER (42)
1 Male
2 Female
3 Not traced

2.22 AGE OF DRIVER (43 44)
(Years estimated if necessary)

2.23 BREATH TEST (45)
0 Not applicable
1 Positive
2 Negative
3 Not requested
4 Failed to provide
5 Driver not contacted at time

2.24 HIT AND RUN (46)
0 Other
1 "Hit and run"
2 Non-stop vehicle, not hit

2.25 DTp SPECIAL PROJECTS (47 48 49 50)

Stats 19B (Rev May 1983)

FIG. 2.1B Stats 19 accident reporting form - vehicle record

CASUALTY RECORD

3.1 RECORD TYPE (1 2) [3][ ]
1 New casualty record
5 Amended casualty record

3.2 POLICE FORCE (3 4) [ ][ ]

3.3 ACCIDENT REF NO (5 6 7 8 9 10 11) [ ][ ][ ][ ][ ][ ][ ]

3.4 VEHICLE REF NO (12 13 14) [ ][ ][ ]

3.5 CASUALTY REF NO (15 16 17) [ ][ ][ ]

3.6 CASUALTY CLASS (18) [ ]
1 Driver or rider
2 Vehicle or pillion passenger
3 Pedestrian

3.7 SEX OF CASUALTY (19) [ ]
1 Male
2 Female

3.8 AGE OF CASUALTY (20 21) [ ][ ]
(Years, estimated if necessary)

3.9 SEVERITY OF CASUALTY (22) [ ]
1 Fatal
2 Serious
3 Slight

3.10 PEDESTRIAN LOCATION (23 24) [ ][ ]
00 Not pedestrian
01 In carriageway crossing on pedestrian crossing
02 In carriageway crossing within zig-zag lines approach to the crossing
03 In carriageway crossing within zig-zag lines exit the crossing
04 In carriageway crossing elsewhere within 50 metres of pedestrian crossing
05 In carriageway crossing elsewhere
06 On footway or verge
07 On refuge or central island or reservation
08 In centre of carriageway not on refuge or central island
09 In carriageway not crossing
10 Unknown

3.11 PEDESTRIAN MOVEMENT (25) [ ]
0 Not pedestrian
1 Crossing from drivers nearside
2 Crossing from drivers nearside–masked by parked or stationary vehicle
3 Crossing from drivers offside
4 Crossing from drivers offside–masked by parked or stationary vehicle
5 In carriageway stationary–not crossing (standing or playing)
6 In carriageway stationary–not crossing (standing or playing)–masked by parked or stationary vehicle
7 Walking along in carriageway facing traffic
8 Walking along in carriageway back to traffic
9 Unknown

3.12 PEDESTRIAN DIRECTION (26) [ ]
Compass point bound
1 N
2 NE
3 E
4 SE
5 S
6 SW
7 W
8 NW
or 0 – Pedestrian–standing still

3.13 SCHOOL PUPIL CASUALTY (27) [ ]
0 Not a school pupil
1 Pupil on journey to/from school
2 Pupil NOT on journey to/from school

3.14 SEAT BELT USAGE (28) [ ]
0 Not car or van
1 Safety belt in use
2 Safety belt fitted–not in use
3 Safety belt not fitted
4 Child safety belt/harness fitted–in use
5 Child safety belt/harness fitted–not in use
6 Child safety belt/harness not fitted
7 Unknown

3.15 CAR PASSENGER (29) [ ]
0 Not car passenger
1 Front seat car passenger
2 Rear seat car passenger

3.16 PSV PASSENGER (30) [ ]
0 Not a PSV passenger
1 Boarding
2 Alighting
3 Standing passenger
4 Seated passenger

3.17 DTp SPECIAL PROJECTS (31 32 33 34) [ ][ ][ ][ ]

FIG. 2.1C Stats 19 accident reporting form – casualty record

The recording of the exact location of an accident is very important. In an urban area the location can usually be defined more precisely than in a rural area because of the proximity of road junctions and major reference features. The Stats 19 form requires the grid reference to be defined (to the nearest ten or one hundred metres). This is established by pinpointing the accident spot on a map of appropriate scale, on the basis of the location description. Unfortunately, assigning a grid reference in this way will often impart a spurious precision to a location which was originally vaguely defined.

Most police forces now have their accident records stored on computer, thus greatly improving data accessibility and making it easier to carry out accident studies. The Metropolitan Police, in collaboration with the GLC, were amongst the first to computerise their records. The principal source of accident data for the present study was the GLC accident data bank, known as ACCSTATS, in which is stored details of all personal injury accidents reported on roads in London since January 1970. Excluded from ACCSTATS (and from this study) are accidents in the City of London - about 1% of the London total. The ACCSTATS data bank is described in Appendix A. The location network used in ACCSTATS is a system of nodes, links and cells. A node is a junction between two classified roads; a link is a length of classified road joining two nodes; a cell is a half-kilometre square. Using the grid reference and route number recorded on the Stats 19 form the computer assigns the accident record to a node, a link or a cell. Thus, all accidents on classified roads are filed to nodes or links and the accidents on minor roads are filed to cells. Within each of the 32 London boroughs each node has a unique three-digit reference number. Each link reference number is simply a combination of the reference numbers of the nodes at either end of the link. Each cell reference number is the grid reference of the south-west corner of the half-kilometre square. A point on a link can be defined in terms of either its grid reference or its distance along the link from node A to node B.

Except where stated otherwise the national statistics quoted in this study were obtained from the DTp publication "Road Accidents Great Britain 1980" (1). The London statistics were compiled from data extracted from ACCSTATS using GLC retrieval programs. There are very slight inconsistencies in accident totals within and between certain of the tables presented. These arise mainly when the information on some of the accident records is incomplete. A particular incomplete record may be acceptable for some tabulations but not for others.

2.2 ACCIDENT RATES (1980)

2.2.1 Accident totals.

In 1980 there were about 250,000 personal injury accidents on roads in Great Britain. Arising from these accidents were 330,000 casualties, including 6,000 fatalities. It is interesting to note that these totals are somewhat lower than the 1960 totals, despite a 154% increase in motor traffic between 1960 and 1980.

2.2.2 Accident distribution by area.

Table 2.1 shows accident totals, road lengths and accident densities for different areas in Great Britain in 1980. More than three-quarters of the accidents (76.7%) were in built-up areas (i.e. on roads with a speed limit of 40 mile/h or less). Accident densities were high in built-up areas - 1.4 accidents per km compared with 0.3 in non-built-up areas. The English Metropolitan counties had accident densities ranging from 0.9 to 1.6 accidents per km compared with the Shire counties' average of 0.6. The accident density in London was particularly high - 3.6 accidents per km. Roads in London account for 4% of the national road network and 18% of the accidents.

The high urban accident densities are undoubtedly due to the high number of road user conflicts which arise in these areas. Junctions are more frequent; pedestrian flows are greater; there is a higher proportion of two-wheeled vehicles and generally more stopping, starting and manoeuvring. In Chapter 6 an examination is made of the effect on London accident rates of traffic flow, roadside development, junctions, pedestrian crossings, bends, gradients and other potential hazards.

Although the high urban accident densities might appear daunting to those involved in accident prevention, they do offer two advantages in implementing accident remedial measures. Fistly, the high accident numbers make it easier to establish the pattern of accidents at individual sites and hence define appropriate remedial measures. Secondly, remedial measures such as localised anti-skid surface treatments can be more cost-effective because the potential accident savings are greater.

TABLE 2.1

Accidents in Great Britain (1980) by area

AREA	n	% of TOTAL	ROAD LENGTH (km)	ACCIDENT DENSITY (acc/km)
GB Total	250,958	100.0	339,480	0.7
England	218,155	86.9	258,690	0.8
Scotland	21,783	8.7	49,450	0.4
Wales	11,020	4.4	31,340	0.4
English shire counties	127,496	50.8	211,014	0.6
London*	45,704	18.2	12,851	3.6
Metropolitan counties	44,624	17.8	34,829	1.3
Greater Manchester	11,106	4.4	7,652	1.5
Merseyside	5,873	2.3	4,103	1.4
South Yorkshire	4,867	1.9	4,996	1.0
Tyne and Wear	3,692	1.5	3,905	0.9
West Midlands	10,303	4.1	6,382	1.6
West Yorkshire	8,783	3.5	7,791	1.1
Built-up areas	192,395	76.7	136,680	1.4
Non-built-up areas	58,552	23.3	202,800	0.3

* All London accident totals in this and subsequent tables exclude accidents occurring in the City of London

SOURCES: Road accidents Great Britain 1980 (1)
ACCSTATS
Transport Statistics Great Britain 1970-1980 (18)
Sabey (19)

2.2.3 Accidents per million vehicle kilometres.

Table 2.2 shows that when the accident rate is expressed in terms of traffic flow, i.e. accidents per million vehicle kilometres (acc/mvkm), the urban rate is more than three times the rural rate - 1.34 compared with 0.40. In London, where about 98% of the roads are classed as being in a built-up area (16), the estimated total motor vehicle flow in 1980 was 25.9 x 10^9 vehicle kilometres (17); thus the overall accident rate was 1.76 acc/mvkm which is 31% higher than for built-up areas generally.

TABLE 2.2

Accidents per million vehicle kilometres in Great Britain (1980) by area

AREA	ACCIDENTS PER MILLION VEHICLE KILOMETRES
GB built-up	1.34
GB non-built-up	0.40
London	1.76

SOURCES: Road Accidents Great Britain 1980 (1)
Munt (17)
ACCSTATS

2.2.4 Distribution of accidents in London.

There is a three-tier administrative structure for roads in London. There are 241 km of Trunk roads which are controlled by the DTp, 1,416 km of Principal roads controlled by the GLC and 11,194 km of Borough roads (of which 1,463 km are classified) which are the responsibility of the individual boroughs. Table 2.3 shows that although the Trunk and Principal roads comprise only 13% of the network they account for 63% of the accidents. The accident density on the Trunk and Principal roads is 17.5 accidents per km compared with 1.5 accidents per km on the Borough roads. Clearly, accident prevention measures such as the improvement of skid resistance are likely to be more cost-effective on the Trunk and Principal roads.

TABLE 2.3

Accidents in London (1980) by road category

ROAD CATEGORY	n	% OF TOTAL	ROAD LENGTH (km)	% OF TOTAL LENGTH	ACCIDENT DENSITY (acc/km)
Trunk	3,364	7.4	241	1.9	14.0
Principal	25,603	56.0	1,416	11.0	18.1
Borough	16,716	36.6	11,194	87.1	1.5
Not coded	21	-	-	-	-
TOTAL	45,704	100.0	12,851	100.0	3.6

SOURCES: 1979 and 80 Annual Abstract of Greater London Statistics (16)
ACCSTATS

The total length of classified road is 3,120 km (24.3% of the network). Table 2.4 shows that 29% of the accidents are at nodes - the major intersections - and 54% are on links - the sections of classified road connecting the nodes. The remaining accidents are on the unclassified, mainly residential roads and are assigned to cells.

TABLE 2.4

Distribution of accidents in London (1980)
between nodes, links and cells

	n	% OF TOTAL
Node	13,415	29.4
Link	24,738	54.1
Cell	7,551	16.5
TOTAL	45,704	100.0

A high proportion of the accidents in London are at road junctions. Table 2.5 shows that 70% of the accidents were at or within 20 metres of a junction. This is close to the average for built-up areas generally and is about double the percentage for non-built-up areas. It is interesting to note that accidents at urban junctions account for more than 50% of all accidents in Great Britain. Junctions are, of course, very frequent on urban roads. Charlesworth (20) reported that the junction frequency on urban roads was 5.8 per km compared with 1.2 per km on rural roads. In the accident risk study described in Chapter 6 it is shown that the average junction frequency on Principal roads in a typical London borough (Borough B) is 10.1 per km. Assuming that the average width of the side road at each junction is 8 metres, the "junction" (i.e. within 20 metres of the kerb line) extends for 48 metres. Thus, junctions constitute 48% of the road length in Borough B (or slightly less if allowance is made for overlaps).

TABLE 2.5

Accidents in Great Britain (1980) at Junctions

AREA	AT JUNCTION	NOT AT JUNCTION	% AT JUNCTION
GB total	146,386	104,554	58.3
Built-up	127,416	64,968	66.2
Non-built-up	18,966	39,579	32.4
London	31,915	13,789	69.8

Pedestrian crossings and light-controlled junctions are high-risk areas where accidents tend to cluster. Table 2.6 shows that 12.2% of the accidents in London were at or within 50 metres of a Pelican or Zebra crossing. A further 15.4% were at or within 20 metres of a light-controlled junction.

TABLE 2.6

Accidents (1980) at pedestrian crossings and light-controlled junctions in London

LOCATION	n	% OF TOTAL
London total	45,704	100.0
Zebra crossings	4,616	10.1
Pelican crossings	946	2.1
ATS junctions	7,044	15.4

2.3 WET-ROAD ACCIDENTS

When rain falls the risk of an accident increases because of reduced skid resistance and impairment of visibility. Both of these effects persist after the rainfall has ceased. Spray will continue to be thrown up for some time afterwards and the skid resistance will remain ~~low~~ impaired for as long as the road remains even slightly wet. In

London rain is falling for about 5% of the time (21) and road surfaces are wet for about 27% of the time (22). The rate at which the road surface dries out will, of course, depend on the ambient conditions. In the winter months, with lower temperatures and fewer hours of daylight, evaporation rates are low and the road will remain wet for much longer than in the summer months. Sabey (23) reported that in 1969 at Crowthorne the roads were wet for 28% of daylight hours and 40% of dark hours.

Table 2.7 shows wet-road accident rates for different areas in Great Britain in 1980. The road surface was reported as being wet in 33.4% of all accidents. In London the wet-road rate was exceptionally low - only 26.4%. This is perhaps due to the fact that in London the rainfall is relatively low (515 mm in Central London in 1980 compared with a mean of 979 mm in England and Wales as a whole), the temperature is high (a mean of 11.4°C in 1980 compared with 9.9°C nationally) (24,25) and the roads are heavily trafficked. In built-up areas generally the wet-road rate was lower than in non-built-up areas - 32.4% compared with 36.8%.

TABLE 2.7

Accidents in Great Britain (1980) by area and road surface condition

AREA	ROAD SURFACE CONDITION			% WET	DRY/WET RATIO
	DRY	WET	SNOW/ICE		
GB total	158,839	83,918	8,172	33.4	1.9
England	140,127	71,460	6,539	32.8	2.0
Scotland	11,935	8,525	1,323	39.1	1.4
Wales	6,777	3,933	310	35.7	1.7
English shire counties	79,725	42,999	4,756	33.7	1.9
London	33,160	12,062	482	26.4	2.7
Metropolitan counties	26,995	16,329	1,301	36.6	1.7
Greater Manchester	6,515	4,280	311	38.5	1.5
Merseyside	3,773	1,996	104	34.0	1.9
South Yorkshire	3,065	1,669	133	34.3	1.8
Tyne and Wear	2,232	1,350	111	36.6	1.7
West Midlands	6,183	3,803	317	36.9	1.6
West Yorkshire	5,227	3,231	325	36.8	1.6
Built-up areas	125,832	62,353	4,180	32.4	2.0
Non built-up areas	33,002	21,553	3,989	36.8	1.5

Codling (26) has estimated that the increase in accident risk on a wet road is such that the number of accidents is about 50% higher than the number expected if the road were dry (all other conditions being the same). Codling's study was on a relatively small scale, involving a total of only 2,000 accidents in six localised areas. By examining meteorological records for each of the areas he was able to define specific wet hours and corresponding dry hours. He then compared accident rates for those hours. In the present study a somewhat different approach was used to obtain an estimate of the excess accidents in London due to wet weather. The principle of the method is to identify 'dry' days by examining the daily accident records, then calculate the average 'dry-day' accident rate for each month of the year and hence estimate what the accident total would be if all the days were dry. Deducting this total from the actual number of accidents gives the excess number of accidents due to precipitation. From this total is deducted the relatively small number of accidents attributable to snow or ice, to give the excess due to wet weather. Details of the procedure and the results are given in Appendix B. Accident records for London for each day in the period 1970-1981 were examined in order to define 'dry' days. Initially a 'dry' day was defined as one on which all the accidents were recorded as occurring on a dry road but because very few such days were found in the winter months the definition was extended to include days on which there were up to two accidents in the wet (out of an average daily total of 135). During the twelve-year period 592,974 accidents were recorded, including 156,117 on wet roads. The estimated excess due to wet weather is 59,200. This is an increase of 11% overall and is equivalent to an increase of 61% in the accident rate when the road is wet, which is of the same order as the 50% increase found by Codling.

It is difficult to estimate how many of the excess wet-road accidents were due to reduced skid resistance and how many were due to reduced visibility, because there is an interaction between the two effects. Reduced visibility in the wet means that a driver is often closer to a hazard before he becomes aware of it; he then has less time and space available to respond by braking or manoeuvring; his frictional demand is then greater but less friction is available. Sabey (27) has estimated that nationally about half of the excess wet-road accidents are due to reduced skid resistance. She arrived at this estimate by comparing wet-road and dry-road skidding rates (the percentage of accidents in each condition which involved skidding); arguing that the difference in skidding rates resulted from the change in skid resistance brought about by the wetness of the road. Table 2.8 shows reported skidding rates on wet and dry roads in London in 1970-81. The difference between the wet and dry rates is equivalent to 16,191 accidents - only 27% of the excess wet-road total and 3% of the grand total for all conditions. This implies that if the wet-road skid resistance of roads in London had been improved so that it was as good as the dry road skid resistance then the overall accident total would have been reduced by only 3%. This estimate is, however, very conservative because it is based on the reported wet-road skidding rate. The actual skidding rate is undoubtedly much greater because many drivers who have skidded are unaware that they have done so and the skid goes unreported. Consequently, the number of accidents resulting from reduced skid resistance in the wet will be greater than is indicated by the skidding accident statistics. The only satisfactory way of estimating the reduction in accidents which could be achieved in practice is to examine the accident rates at sites where the skid resistance has been improved. This approach is adopted in Chapter 7.

TABLE 2.8

Skidding rates (1970-81) in London by road surface condition

CONDITION	SKIDDING ACCIDENTS	ALL ACCIDENTS	% SKID
Dry	9,167	428,964	2.1
Wet	19,129	156,117	12.3
Snow/ice	3,165	7,893	40.1
TOTAL	31,461	592,974	5.3

2.4 SKIDDING ACCIDENTS

Police officers recording the details of an accident are required to note on the Stats 19 form whether skidding was involved. A vehicle is considered to be skidding when one or more of its wheels are locked. There is not necessarily any lateral displacement of the vehicle. In interpreting skidding accident statistics it must be recognised that there is considerable under-reporting of skidding. Many drivers involved in an accident may not be aware that they have skidded and some drivers are reluctant to admit that they have done so because they fear that the police would consider it to be an admission of careless driving or excessive speed. Transient skid marks on a wet road may have disappeared by the time the police arrive at the scene and bystanders who may have seen the vehicle skid would usually divulge the information only if they were asked directly by the police.

Table 2.9 shows reported skidding rates in 1980 for different areas and road surface conditions. Skidding was reported in 51,823 out of a grand total of 250,929 accidents - an overall skidding rate of 20.7%. Of the skidding accidents 6,128 were on snow or ice, 23,677 on wet roads and 22,018 in the dry.

Skidding was reported in 75% of the accidents which occurred on snow or ice-covered roads. This very high skidding rate indicates that there is considerable scope for reduction of such accidents by improved winter maintenance and, perhaps, by driver education. The snow/ice skidding accidents accounted for 2.4% of all accidents in 1980 which had a relatively mild winter. The average number of skidding accidents on snow or ice in the years 1970-1980 was equivalent to 3.0% of all accidents (28).

On dry roads the skidding rate was 13.9% overall, 10.0% in built-up areas and 28.0% in non-built-up areas. The higher rate in non-built-up areas must be largely attributable to higher vehicle speeds. It is interesting to note that there were almost as many skidding accidents on dry roads as on wet ones. This is surprising since skidding is not usually thought of as a particular problem on dry roads. Skid resistance levels are high on almost all road surfaces when they are dry and there would appear, therefore, little that can or need be done to the road surface to increase dry-road skid resistance. Dry-road skidding could be reduced by further improvements in vehicle handling and in tyre performance, by driver education and by engineering measures at skidding sites either to eliminate hazards or at least increase driver awareness of them.

AREA	DRY			WET			SNOW/ICE			TOTAL		
	Skid	Total	% Skid	Skid	Total	% Skid	Skid	Total	% Skid	Skid	Total	% Skid
GB Total	22,018	158,839	13.9	23,677	83,918	28.2	6,128	8,172	75.0	51,823	250,929	20.7
England	18,653	140,127	13.3	19,760	71,460	27.7	4,791	6,539	73.3	43,204	218,126	19.8
Scotland	2,019	11,935	16.9	2,717	8,525	31.9	1,091	1,323	82.5	5,827	21,783	26.8
Wales	1,346	6,777	19.9	1,200	3,933	30.5	246	310	79.4	2,792	11,020	25.3
Shire counties	15,073	79,725	18.9	14,760	42,999	34.3	3,721	4,756	78.2	33,554	127,480	26.3
London	634	33,160	1.9	1,203	12,062	10.0	165	482	34.2	2,002	45,704	4.4
Met.counties	2,920	26,995	10.8	3,775	16,329	23.1	901	1,301	69.3	7,596	44,625	17.0
Greater Manchester	736	6,515	11.3	1,061	4,280	24.8	206	311	66.2	2,003	11,106	18.0
Merseyside	410	3,773	10.9	438	1,996	21.9	59	104	56.7	907	5,873	15.4
South Yorkshire	331	3,065	10.8	337	1,669	20.2	100	133	75.2	768	4,867	15.8
Tyne and Wear	211	2,232	9.5	375	1,350	27.8	82	111	73.9	668	3,693	18.1
West Midlands	635	6,183	10.3	883	3,803	23.2	212	317	66.9	1,730	10,303	16.8
West Yorkshire	597	5,227	11.4	681	3,231	21.1	242	325	74.5	1,520	8,783	17.3
Kent	912	4,530	20.1	792	2,159	36.7	146	206	70.9	1,850	6,895	26.8
Surrey	500	3,637	13.7	609	1,829	33.3	168	217	77.4	1,277	5,683	22.5
Buckinghamshire*	174	811	21.5	206	585	35.2	54	83	65.1	434	1,479	29.3
Hertfordshire	387	2,595	14.9	486	1,537	31.6	122	173	70.5	995	4,305	23.1
Essex	984	4,292	22.9	1,110	2,290	48.5	205	246	83.3	2,299	6,828	33.7
Built-up areas	12,599	125,571	10.0	14,176	62,192	22.8	2,648	4,162	63.6	29,423	191,925	15.3
Non Built-up areas	9,384	32,943	28.0	9,426	21,467	43.9	3,417	3,941	86.7	22,227	58,351	38.1

* Buckinghamshire figures exclude a number of accidents for which details were not available
SOURCES: (i) Amendment to Road Accidents Great Britain 1980 (ii) ACCSTATS

TABLE 2.9 Skidding rates in Great Britain (1980) by area and road surface condition

Skidding was reported in 28.2% of accidents on wet roads - about double the rate on dry roads. The wet-road rate was 22.8% in built-up areas and 43.9% in non-built-up areas. In London the wet skidding rate was only 10.0% which is much lower than in the Metropolitan counties, where the rate ranged from 21.1% to 27.8% with a mean of 23.1%. It is also much lower than in the five adjoining counties which ranged from 31.6% (Hertfordshire) to 48.5% (Essex). For some years the GLC has been carrying out a major programme of localised skid resistance improvements and has endeavoured to increase general skid resistance levels by using polish-resistant aggregates in routine resurfacing. This policy has undoubtedly helped to reduce skidding accidents in London but does not itself account for the rate being very low, because it was already much lower than elsewhere before the improvement programme started (29,30). It is most probably the consequence of low vehicle speeds. The pattern of skidding accidents in London is examined in Section 2.5.

On wet road surfaces there is considerable variation in skid resistance and many sections of road, particularly on heavily-trafficked routes, become extremely slippery. It has been demonstrated (31) that skidding accidents can be reduced at individual locations by increasing the skid resistance substantially. Since the wet-road skidding rate is double the dry-road rate, there is clearly great potential for accident reduction by improving wet-road skid resistance. Although it might be considered desirable to provide very high wet-road skid resistance on all roads, it is technically difficult (see Chapter 4) and expensive (see Chapter 9) to do so. It is important that dangerously slippery areas should be eliminated but it is also important to ensure that target skid resistance levels should be related to the actual needs at particular sites and that the expenditure required can be justified in terms of the likely saving in accident costs.

2.5 WET-ROAD SKIDDING ACCIDENTS IN LONDON.

2.5.1 Introduction.

This section briefly examines the pattern of wet-road skidding accidents in London. It is established partly by examination of the wet-road skidding accidents alone but mainly by comparing them with wet-road accidents generally. Consideration is given to those aspects which might be of relevance in defining strategies to reduce skidding rates. Only the information contained on the Stats 19 form is considered at this stage. This does not include items such as skid resistance, traffic flow and site geometry. These additional factors are considered in Chapter 5 and in Chapters 6 and 7 which deal with the assessment of accident risk and the relationship between accidents and skid resistance. Information on all wet-road accidents reported in London (excluding the City of London) in the years 1979-81 was extracted from the ACCSTATS data bank using the GLC retrieval programs described in Appendix A.

2.5.2 Month-by month variation.

Table 2.10 shows accidents in London in 1979-81 tabulated by month and road surface condition. In the three years there was a total of 137,194 accidents of which 36,941 (26.9%) were on wet roads. Skidding was reported in 3,554 (9.6%) of the wet-road accidents. There is a marked seasonal trend in the wet-road skidding rates, with the rates being higher in summer and lower in winter. The highest rate was in August (14.4%) and the lowest in December (7.3%). The May to September rates are all substantially higher than the average; the November, December, January and March rates are all lower. This pattern in skidding rate reflects the seasonal variation in skid resistance which is discussed in Chapter 3. Although the wet-road skidding rate (i.e. the proportion of wet-road accidents in which skidding is reported) is highest in the summer months, the actual number of wet-road skids is then relatively low because the roads are wet for only a small proportion of the time.

Month	DRY			WET			SNOW/ICE			TOTAL		
	Skid	Total	% Skid	Skid	Total	% Skid	Skid	Total	% Skid	Skid	Total	% Skid
January	114	5,604	2.0	316	3,837	8.2	424	1,262	33.6	854	10,703	8.0
February	154	6,825	2.3	226	2,609	8.7	215	539	39.9	595	9,973	6.0
March	118	6,479	1.8	416	5,214	8.0	35	113	31.0	569	11,806	4.8
April	163	8,401	1.9	233	2,204	10.6	5	26	19.2	401	10,631	3.8
May	185	9,063	2.0	287	2,606	11.0	-	8	-	472	11,677	4.0
June	219	9,266	2.4	247	1,840	13.4	-	7	-	466	11,113	4.2
July	196	9,609	2.0	259	1,970	13.1	-	8	-	455	11,595	3.9
August	188	9,157	2.1	214	1,488	14.4	-	7	-	402	10,652	3.8
September	175	9,917	1.8	223	1,986	11.2	-	10	-	398	11,913	3.3
October	165	9,147	1.8	421	4,273	9.9	1	8	12.5	587	13,428	4.4
November	149	7,754	1.9	401	4,670	8.6	33	119	27.7	583	12,543	4.6
December	127	5,920	2.1	311	4,236	7.3	300	1,004	29.9	738	11,160	6.6
TOTAL	1,953	97,142	2.0	3,554	36,941	9.6	1,013	3,111	32.6	6,520	137,194	4.8

TABLE 2.10 Skidding rates in London (1979-81) by month and road surface condition

2.5.3. Time of day.

Table 2.11 shows that the greatest numbers of wet skids occur during the morning and evening peak traffic periods but the skidding rate is actually below the average of 9.6% in these periods. The skidding rate is extremely high (24.6%) between 5 and 6 am, which probably reflects the fact that high speeds are more likely at that time of the morning when traffic is very light.

TABLE 2.11

Wet-road accidents in London (1979-81) by time of day and skidding rate

TIME OF DAY	WET-ROAD ACCIDENTS		
	SKID	TOTAL	% SKID
00.00-00.59	100	1,056	9.5
01.00-01.59	73	642	11.4
02.00-02.59	84	537	15.6
03.00-03.59	31	294	10.5
04.00-04.59	36	195	18.5
05.00-05.59	48	266	24.6
06.00-06.59	86	575	15.0
07.00-07.59	188	1,581	11.9
08.00-08.59	231	2,547	9.1
09.00-09.59	175	1,838	9.5
10.00-10.59	126	1,362	9.3
11.00-11.59	142	1,477	9.6
12.00-12.59	170	1,675	10.1
13.00-13.59	177	1,711	10.3
14.00-14.59	197	1,627	12.1
15.00-15.59	215	2,099	10.2
16.00-16.59	236	2,564	9.2
17.00-17.59	216	2,858	7.6
18.00-18.59	210	2,358	8.9
19.00-19.59	173	2,100	8.2
20.00-20.59	145	1,789	8.1
21.00-21.59	142	1,637	8.7
22.00-22.59	158	1,738	9.1
23.00-23.59	195	2,415	8.1
TOTAL	3,554	36,941	9.6

2.5.4 Weather.

Table 2.12 shows that during rainfall the skidding rate is slightly above the average wet-road rate (10.1% compared with a mean of 9.6%). This is to be expected for two reasons. Firstly, the impaired visibility is likely to increase the probability of emergency braking or manoeuvring. Secondly, the thickness of the water film on the road is likely to be greater during the actual rainfall and this could further reduce the skid resistance.

TABLE 2.12

Wet-road skidding rates in London (1979-81) by weather

WEATHER	ACCIDENTS ON WET ROADS		
	SKID	TOTAL	% SKID
Fine	1,289	14,452	8.9
Raining	2,211	21,869	10.1
Snowing	41	476	8.6
Fog	13	144	9.0
TOTAL	3,554	36,941	9.6

2.5.5. Light conditions.

Table 2.13 shows that the wet-road skidding rate is higher than average in daylight and lower in the dark with street lights on. This is a surprising result and is the reverse of what might be expected. The impaired visibility during the hours of darkness would have been expected to give a higher rate. It is possible that drivers are aware of the greater risk and reduce their speed accordingly. It is also possible that the true daylight wet-skidding rate is not higher but simply that a daylight skid is more likely to be detected because visual evidence of the skid (i.e. transient skid marks on the road or eye-witnesses observing locked wheels) is more apparent. Even during rainfall the skidding rate is lower in the dark (with street lights on) than in daylight (Table 2.14). It should be noted that almost all roads in London are illuminated at night to a high standard. Less than 1% of all wet-road accidents occurred in the dark on roads which were unlit.

TABLE 2.13

Wet-road skidding rates in London (1979-81) by light condition

LIGHT CONDITION	ACCIDENTS ON WET ROADS		
	SKID	TOTAL	% SKID
Day	2,190	20,950	10.5
Dark, street lights on	1,337	15,732	8.5
Dark, no street lights	27	259	10.4
TOTAL	3,554	36,941	9.6

TABLE 2.14

Wet-road skidding rates in London (1979-81)

by light condition and weather

LIGHT CONDITION	WET/RAINING			WET/NOT RAINING *		
	SKID	TOTAL	% SKID	SKID	TOTAL	% SKID
Day	1,360	12,171	11.1	796	8,418	9.5
Dark, street lights on	839	9,558	8.7	479	5,918	8.1
Dark, no street lights	12	140	8.6	14	116	12.1
TOTAL	2,211	21,869	10.1	1,289	14,452	8.9

* excluding accidents in fog or snow

2.5.6 Vehicle type.

Table 2.15 gives details of the vehicles involved in wet-road skidding accidents. There were 36,941 accidents involving 66,022 vehicles of which 3,648 (5.5%) were reported to have skidded. Cars accounted for 61% of all skids but had a lower than average skidding rate (4.8%). The next largest vehicle group was powered two-wheelers (motorcycles, scooters and mopeds) which accounted for 26% of skids and had a very high overall skidding rate of 12.0%, more than double the average rate. This is not surprising in view of the inherent instability of this class of vehicle. Light goods vehicles had a low skidding rate but heavy goods vehicles had a skidding rate of 7.2% . The high h.g.v. skidding rates are possibly due to the relatively inferior wet friction properties of most h.g.v. tyres (32).

TABLE 2.15

Vehicles involved in wet-road accidents in London (1979-81) by vehicle type and skidding rate

TYPE OF VEHICLE	SKIDDING VEHICLES	ALL VEHICLES	SKIDDING RATE (%)
Pedal cycle	39	2,587	1.5
Powered two-wheeler	950	7,884	12.0
Car	2,216	46,470	4.8
PSV	74	2,009	3.7
Goods up to 1.5t (lgv)	212	4,197	5.1
Goods over 1.5t (hgv)	129	1,801	7.2
Other	27	1,051	2.6
TOTAL	3,648	66,022	5.5

2.5.7. Driver age.

Table 2.16 shows skidding rates for different age groups of car drivers. There is a very distinct reduction of skidding rate with increasing age, ranging from 10.2% for drivers aged 19 and under down to 2.8% for those aged 65 and over. This indicates that with experience drivers do learn to avoid skids and suggests that there is a need for more emphasis on skid prevention in driver training. It also reflects the fact that vehicle speeds tend to decrease with increasing driver age.

TABLE 2.16

Car drivers involved in wet-road accidents in London (1979-81) by age and skidding rate

AGE OF DRIVER	WET-ROAD ACCIDENTS		
	SKID	TOTAL	% SKID
under 17	5	54	9.3
17	50	425	11.8
18	95	984	9.7
19	126	1,244	10.1
20	121	1,462	8.3
21	103	1,357	7.6
21-24	255	4,015	6.4
25-28	273	4,979	5.5
29-34	350	6,695	5.2
35-54	504	12,748	4.0
54-64	124	3,448	3.6
65+	42	1,507	2.8
Unknown	168	7,552	2.2
TOTAL	2,216	46,470	4.8

2.5.8. Road category.

Table 2.17 shows the wet-road skidding rate for the three categories of road in London. 63.5% of the skidding accidents were on the Trunk and Principal roads. The skidding rate on the Trunk roads was 13.1% which is substantially higher than the average rate of 9.6%. This is probably because vehicle speeds are generally higher on the Trunk roads. Skidding rates on Principal roads are below average (9.0%) and on Borough roads slightly above (9.7%). Wet-road skidding accident densities on Trunk and Principal roads were 0.58 and 0.43 accidents per kilometre per annum. On unclassified Borough roads the density was extremely low - only 0.02 accidents per km per annum, or one accident for every 52 km of road.

TABLE 2.17

Wet-road skidding rates in London (1979-81) by road category

ROAD CATEGORY	ACCIDENTS ON WET ROADS		
	SKID	TOTAL	% SKID
Trunk	420	3,205	13.1
Principal	1,837	20,397	9.0
Borough classified	734	7,697	9.5
Borough unclassified	561	5,626	10.0
Not coded	2	16	-
TOTAL	3,554	36,941	9.6

2.5.9. Speed limit of road.

Table 2.18 shows that skidding rates are substantially higher on roads with a 40 mile/h speed limit compared with 30 mile/h and even higher at speed limits above 40 mile/h.

TABLE 2.18

Wet-road skidding rates in London (1979-81) by speed limit of road

SPEED LIMIT (mile/h)	ACCIDENTS ON WET ROADS		
	SKID	TOTAL	% SKID
30	3,057	33,411	9.1
40	296	2,293	12.9
50	80	430	18.6
60	29	180	16.1
70	92	627	14.7
TOTAL	3,554	36,941	9.6

2.5.10. Nodes, links and cells.

Table 2.19 shows the distribution of wet-road skidding accidents between nodes, links and cells. About 84% of the skidding accidents were on the nodes and links, which constitute the classified portion of the road network and account for 24.3% of the road length. The skidding rate at the nodes - the junctions between classified roads - was lower than average, 7.8% compared with the average of 9.6% (but see Section 2.5.11).

TABLE 2.19

Wet-road skidding rates at nodes, links and cells in London (1979-81)

	ACCIDENTS ON WET ROADS		
	SKID	TOTAL	% SKID
Node	830	10,645	7.8
Link	2,163	20,670	10.5
Cell	561	5,626	10.0
TOTAL	3,554	36,941	9.6

2.5.11. Junctions.

Tables 2.20 and 2.21 give details of wet-road skidding accidents at junctions. Over 60% of the skidding accidents were at or within 20 metres of a junction but the skidding rate was 8.2% compared with 13.0% away from junctions. Crossroad junctions had a lower rate (5.7%) than average. Other types of junction had rates above average. Light-controlled (ATS) junctions had a lower rate (6.8%) than uncontrolled junctions (8.6%). The accidents at the light-controlled junctions accounted for 10.2% of all wet-road skidding accidents.

TABLE 2.20

Wet-road skidding rates in London (1979-81) by junction type

JUNCTION TYPE	ACCIDENTS ON WET ROADS		
	SKID	TOTAL	% SKID
Roundabout	140	1,287	10.9
T or staggered	1,320	14,693	9.0
Y	79	657	12.0
Crossroads	409	7,205	5.7
Multiple	66	769	8.6
Private drive	32	590	5.4
Other	92	828	11.1
All junctions	2,138	26,029	8.2
Not within 20m	1,416	10,912	13.0
GRAND TOTAL	3,554	36,941	9.6

TABLE 2.21

Wet-road skidding rates in London (1979-81)

by junction type and junction control

JUNCTION TYPE	ATS-CONTROLLED			NON-ATS		
	SKID	TOTAL	% SKID	SKID	TOTAL	% SKID
Roundabout	7	61	11.5	143	1,286	11.1
T or staggered	121	1,215	10.0	1,199	13,478	8.9
Y	10	102	9.8	69	555	12.4
Crossroads	181	3,374	5.4	228	3,831	6.0
Multiple	37	456	8.1	29	313	9.3
Private drive	-	5	-	32	585	5.5
Other	6	126	4.8	86	702	12.3
TOTAL	362	5,339	6.8	1,786	20,750	8.6

2.5.12. Pedestrian crossings.

Table 2.22 shows that the skidding rate at zebra crossings (9.3%) was slightly below the average (9.6%) and at pelican crossings the rate was very low (6.2%). Nevertheless, zebra and pelican crossings account for 12.2% of all wet skidding accidents. It is interesting that the skidding rate at pelican crossings is very low compared with that at zebra crossings and is in fact very similar to the rate at light-controlled junctions. A possible explanation is that at zebra crossings emergency braking and consequent skidding are more likely to occur because, in stepping out on the road to assert their right of precedence, pedestrians often misjudge the ability of approaching vehicles to stop in time whereas at pelican crossings and light-controlled junctions the pedestrian does not have to exercise any judgement but simply has to wait for the vehicles to stop in response to the traffic signals. An additional reason for the low rate at pelican crossings is that at a high proportion of them anti-skid surfacing has been laid on the approaches as a matter of routine. This policy resulted from a GLC study (33) which showed that when a zebra crossing was converted to a pelican there was no safety benefit unless anti-skid surfacing and pedestrian guard railing were also installed.

TABLE 2.22

Wet-road skidding rates at pedestrian crossings and light-controlled junctions in London (1979-81)

LOCATION	WET ROAD ACCIDENTS		
	SKID	TOTAL	% SKID
All locations	3,554	36,941	9.6
Zebra crossings	383	4,125	9.3
Pelican crossings	51	819	6.2
ATS junctions	362	5,340	6.8

2.5.13. Possible distortion resulting from GLC anti-skid surfacing programme.

The possibility must be considered that the below-average skidding rates at pedestrian crossings and light-controlled junctions is not an indication that they are inherently less skid-prone than other locations but is simply a consequence of the GLC anti-skid surfacing programme which has been directed mainly at such sites. Anti-skid surfacing has been laid on the approaches to approximately one-third of all pedestrian crossings and light-controlled junctions in London and has undoubtedly reduced accident rates. Table 2.23 shows skidding rates in 1970 when the programme was in its early stages and only a small number of sites had been treated. It will be seen that even at that time the skidding rates at the pedestrian crossings and the signalled junctions were substantially below the average for all locations. Thus it may be concluded that these sites really are less skid-prone. A possible explanation is that drivers tend to reduce their speed when they approach pedestrian crossings or traffic signals and are poised ready to brake in a controlled manner if necessary. The overall accident rate is high at these locations because they are major conflict areas but the likelihood that an accident will involve skidding is less than at other locations.

TABLE 2.23

Wet-road skidding rates at pedestrian crossings and light-controlled junctions in London (1970)

LOCATION	WET ROAD ACCIDENTS		
	SKID	TOTAL	% SKID
All locations	2,233	14,446	15.4
Zebra crossings	102	969	10.5
Pelican crossings	1	20	(5.0)
ATS junctions	264	2,121	12.4

2.5.14. Summary.

This preliminary examination of wet-road skidding accidents in London has produced few surprises apart from the extremely low reported skidding rates compared with other urban areas. Skidding rates across the spectrum of road users, road types and location types were broadly uniform. As might be expected, higher than average skidding rates were revealed for young drivers, for powered two-wheelers, for roundabouts and for roads with speed limits above 30 mile/h. The skidding rates at pedestrian crossings and light-controlled junctions were shown to be below average, due only in part to the GLC anti-skid surfacing programme but, because they are high accident density locations, these sites account for about a quarter of all reported skidding accidents and continue to represent a major target for accident prevention measures.

CHAPTER 3

ROAD SURFACE SKID RESISTANCE

3.1 MECHANICS OF SKIDDING

A vehicle will skid when, in braking, accelerating or manoeuvring, the frictional demand exceeds the limiting friction force that can be generated at the tyre/road interface.

If a small horizontal force is applied to a body of mass m resting on a horizontal surface, motion of the body is resisted by the frictional force which is developed at the interface between the body and the surface. If the applied force is increased progressively a value will be reached when it is equal to the limiting static frictional force, F, and the body will then start to slide. The limiting frictional force is proportional to the normal reaction at the interface,

$$F = \mu mg$$

where μ is the Coefficient of Static Friction and g is the acceleration due to gravity.

Once the body is actually sliding a lower force is required to sustain motion and μ in this condition is called the Coefficient of Dynamic or Sliding Friction.

The two principal forces acting on a vehicle tyre at the tyre/road interface are the vertical force, W, due to the weight of the vehicle, and a frictional force in the plane of the road surface which is the reaction to the braking force, the driving force or the lateral force on the tyre. Under these conditions rolling resistance is very low compared with the frictional force, as also is the aerodynamic drag at urban vehicle speeds. The frictional force is the sum of an adhesion component which is developed at areas of dry contact between tyre and road and a hysteresis component associated primarily with energy losses in the tyre rubber when the tyre is deformed by particles of coarse aggregate projecting from the road surface. The limiting frictional force, F, has a value given by

$$F = \mu W$$

where μ is the coefficient of friction between the tyre and the road. Since

$$F = Wa/g$$

where a is the acceleration of the wheel, then μ is numerically equal to the acceleration expressed in terms of g.

When the wheel is braked whilst travelling in a straight line on a level surface there are no lateral forces and so, at the limiting condition

$$\mu = \text{braking force/vertical force}$$

The braking force is at its maximum when the wheel is on the point of locking (usually at about 10-20% slip) and μ in this condition is known as the Peak Braking Force Coefficient or the Coefficient of Impending Sliding. When the wheel is actually locked (i.e. at 100% slip) the braking force is lower and μ in this condition is known as the Braking Force Coefficient, BFC. The BFC (when measured with standard equipment under specified conditions) is frequently used as a measure of road surface skid resistance. It would, perhaps, be more logical to use the coefficient of impending sliding rather than the BFC but the latter is easier to measure.

The braking distance, s, of the wheel is given by

$$s = v^2/2a = v^2/2\mu g$$

where v is the initial velocity. This assumes a constant friction coefficient (and deceleration) throughout the velocity range v to zero. For dry road surfaces the coefficient varies only slightly with speed (unless the tyre overheats) but on most wet road surfaces it decreases with increasing speed, depending on the surface roughness (i.e. the texture depth). It is then necessary to use the expression

$$s = \int_0^V (v/\mu g)dv.$$

The minimum braking distance is greater when the wheel is skidding than when it is rotating, because of the lower friction coefficient with the wheel locked. The shortest braking distance is achieved when all the wheels of a vehicle are on the point of locking. Anti-lock braking systems incorporate sensors to monitor the rate of angular acceleration of each wheel and reduce the braking effort on a wheel if it is about to lock. Such systems have been available for many years but, because of the additional cost involved, have as yet been fitted to very few vehicles.

A further complication arises through load transfer. When a vehicle travelling forwards is braked the load increases on the front wheels and decreases on the rear wheels, thus increasing the likelihood of a rear-wheel skid. The more severe the deceleration, the greater will be the degree of load transfer. This is why skidding frequently occurs during braking at higher speeds on dry roads, despite the high friction coefficients on dry road surfaces (typically 0.80 to 1.00). Vehicle manufacturers attempt to offset the effect of load transfer by increasing the proportion of braking effort on the front wheels but this increases the probability that the front wheels will lock, with a consequent loss of directional control.

If there are lateral forces on the wheel, for example when it is travelling on a horizontal curve without braking, the limiting frictional force available to prevent sliding is again given by

$$F = \mu W$$

$$\mu = F/W = \text{sideways force/vertical force}$$

When the wheel is fully slipping μ is known as the Sideway Force Coefficient, SFC. When measured in a specified way the SFC is the standard measure of road surface skid resistance in Great Britain.

The radial acceleration of the wheel is given by

$$a = v^2/r$$

where r is the radius of curvature of the path. Therefore, the sideways (centrifugal) force is

$$F = Wv^2/gr$$

Therefore,

$$\mu = v^2/gr$$

Again μ is equal to the acceleration expressed in terms of g.

When the curve is banked (at angle θ) it is necessary to consider the components of the forces perpendicular to and parallel with the plane of the road. We then have

$$\mu = (v^2 - gr\tan\theta)/(gr + v^2\tan\theta)$$

3.2 FRICTIONAL DEMAND

During normal driving the deceleration levels, and hence frictional demand levels, are relatively low. Drivers identify in good time those situations which require them to slow down or stop and they reduce their speed in a controlled manner, in the light of their knowledge of the braking capability and handling characteristics of their vehicle. They also wish to avoid the physical discomfort caused by rapid deceleration. Similarly, when they negotiate a bend they exercise their judgement and select a speed which they consider will enable them to stay on their selected path without sliding and which will not result in undue discomfort from lateral acceleration. When an emergency situation arises the driver usually applies maximum braking effort which will often lock the wheels. Problems also occur when a driver realises that he is travelling too fast on a bend and then applies the brakes. The braking and centrifugal forces combine to increase the frictional demand. When emergency braking is necessary on a bend the frictional demand can be extremely high.

In a recent survey in London (34) several instrumented vehicles travelled repeatedly round a main road circuit and peak decelerations were measured when the vehicles stopped at pedestrian crossings and traffic lights. Out of a total of 1532 recorded decelerations (of 0.1g and above) only 7 (0.46%) were in excess of 0.40g and none exceeded 0.45g. There were no actual instances of emergency braking throughout the whole exercise despite the fact that some of the roads in the circuit were very heavily trafficked and there were numerous conflict areas. This confirms that at normal urban traffic speeds the level of frictional demand in routine braking is quite low.

A TRRL study (35) of routine braking involving fourteen drivers and a total of 2,500 decelerations during 2,000 km of travel (presumably on rural roads) showed that 80% of the decelerations were below 0.20g, that most of the drivers occasionally required a deceleration of 0.35 to 0.40g and that only 0.2% of the decelerations were in excess of 0.40g. Thus, a friction coefficient of 0.40 would have been sufficient to prevent skidding in 99.8% of the decelerations. Other studies reported by TRRL (35) indicate that on curves the discomfort induced by the lateral acceleration is the major factor limiting frictional demand and that only 10% of vehicles are driven in such a way as to require a coefficient in excess of 0.30, with about 0.1% requiring a coefficient of 0.55.

The DTp design manual (36) for urban roads requires that the radius of curvature and superelevation of a bend should be such that theoretically a friction coefficient of only 0.18 is necessary at design speeds up to and including 30 mile/h (48 km/h) and 0.15 at higher speeds. A typical road surface will enable wet-road coefficients to be generated which are well in excess of these values. There is, therefore, a considerable margin of safety to accommodate either a moderate degree of braking on the bend or vehicle speeds in excess of the design speed. The manual also specifies stopping sight distances such that only a moderate friction coefficient is required.

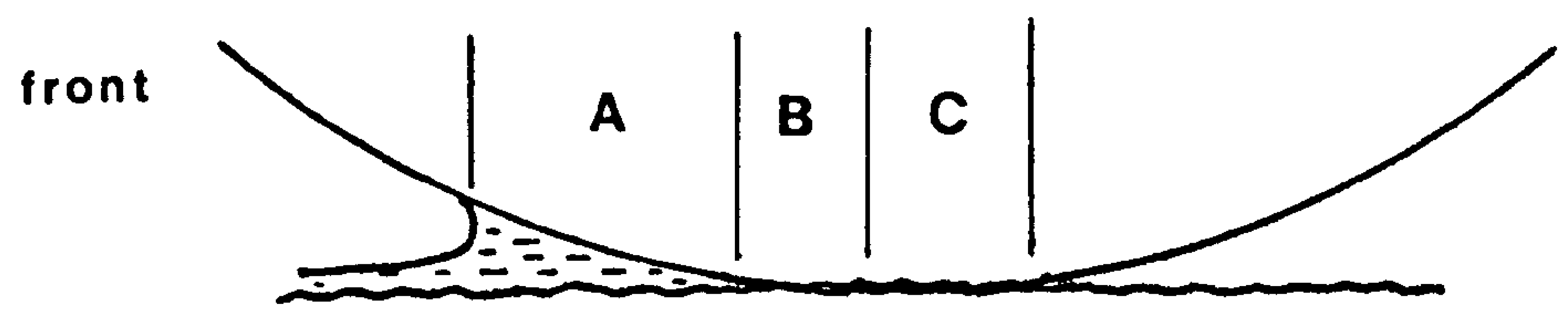
Many existing urban roads are below the geometric standards suggested in the DTp design manual. Consequently, greater reliance is placed on the ability of the driver to assess the appropriate speed or deceleration rate in a given situation. As demonstrated above, the frictional demand in normal driving is low and it is fairly easy to maintain a road surface skid resistance which is adequate for the vast majority of drivers. A small proportion of drivers deliberately drive in a manner that will frequently lead to a high frictional demand (i.e. high speeds, severe braking, harsh manoeuvring) and it is arguable whether high skid resistance levels should be provided to accommodate these drivers (except where their actions endanger other road users). It is, of course, important to identify areas where high deceleration rates are observed relatively frequently and the risk of a skidding accident is high. Consideration should then be given to reducing the accident risk in these areas by providing as high a level of skid resistance as is technically possible or economically justifiable.

In principle it should be possible to define the skid resistance requirements at a particular site by observing the deceleration and/or lateral acceleration rates of individual vehicles at the site and hence deducing the frictional demand levels. Some success has been claimed with this approach in the USA (37) but the method is not wholly satisfactory. It is useful in establishing the pattern of routine frictional demand at a site but requires several thousand observations to define the upper 'tail' of the distribution of frictional demand. Having established the distribution it is then necessary to decide on the cut-off point. If say the 99.9 percentile level of frictional demand is taken as the target this implies that one vehicle in every thousand will skid and this may be unacceptable. If, on the other hand, the 99.999 percentile level is taken the skidding rate would be very low but it may be technically impossible or prohibitively expensive to achieve the target skid resistance level. Furthermore, it has not yet been established that there is a good correlation between skidding rates predicted from observations of deceleration and/or lateral acceleration rates, and with actual skidding rates or, more importantly, with accident rates. In Great Britain the emphasis has been more on establishing the correlation between skid resistance levels and accident risk at different categories of site and hence defining target skid resistance levels. This is discussed further in Chapters 5, 6 and 7.

3.3 FACTORS AFFECTING SKID RESISTANCE.

3.3.1 Surface texture.

When a vehicle is running on a wet road surface it is necessary for the layer of water between the tyre and the road to be dispersed before dry contact can be established and adhesive forces developed. Figure 3.1 shows the three distinct regions at the tyre/road interface. In zone A, at the leading edge of the tyre, the bulk of



A = unbroken wedge of water
B = transition zone
C = 'dry' contact

FIG. 3.1 Tyre/road interaction zones

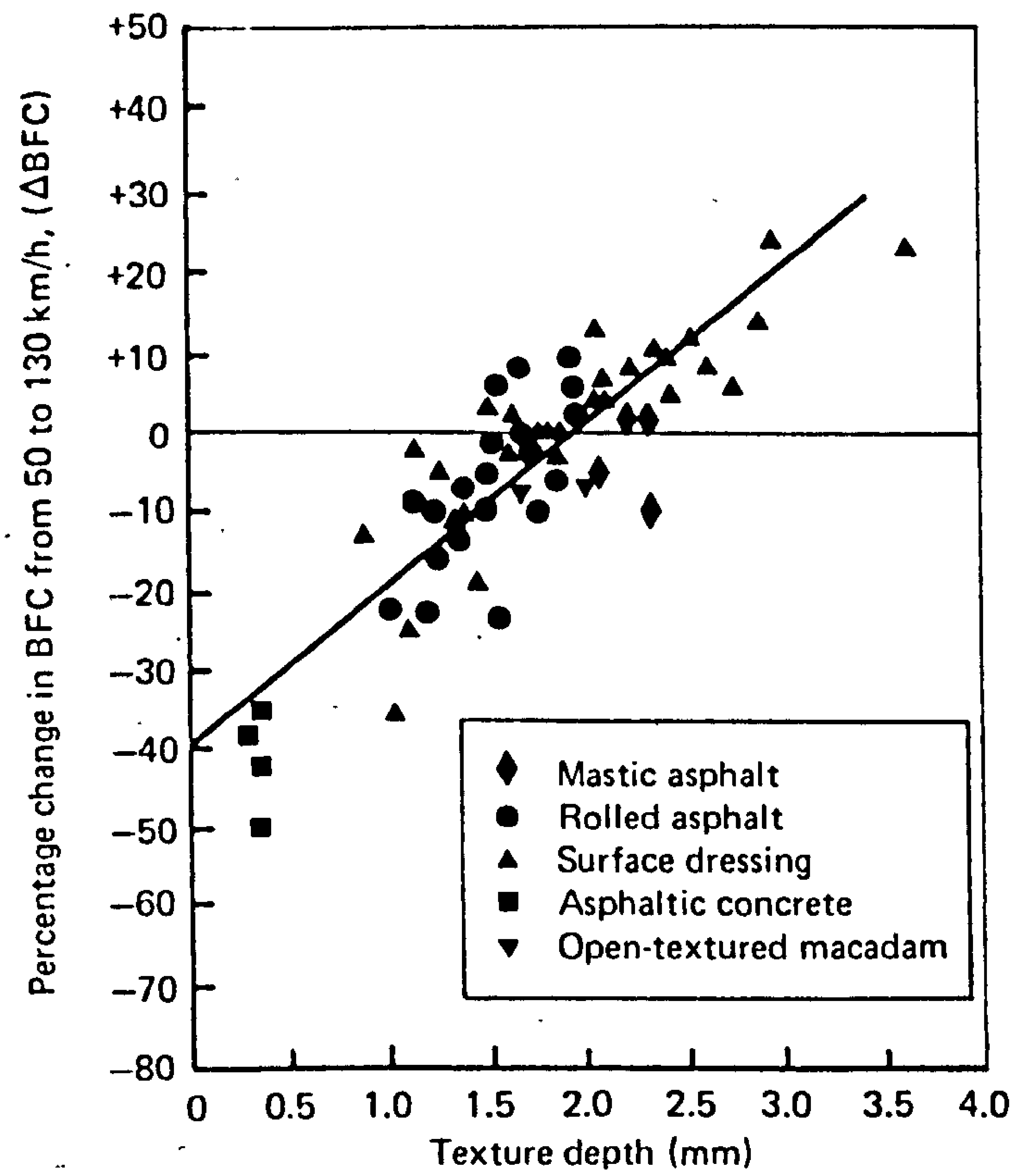


FIG. 3.2 Relationship between texture depth and reduction in BFC between 50 km/h and 80 km/h (55)

the water is dispersed, leaving a thin film which can be penetrated in zone B by some of the surface asperities, with substantially dry contact being achieved in zone C. It has been established (38) that surface asperities of diameter 0.01 to 0.10 mm are most effective in breaking through thin water films. Texture on this scale is known as 'microtexture' and is (for most types of surfacing) effectively the texture of the surface of the individual aggregate particles exposed at the road surface.

At slow vehicle speeds the bulk water is readily dispersed, zone C (the area of dry contact) is large and the maximum adhesive force can be developed. As the vehicle speed increases there is less time available for the removal of the water and zone C becomes smaller, with a consequent reduction in adhesive force. The reduction can be minimised by providing drainage channels to facilitate the removal of bulk water. One way of doing this is to provide drainage grooves on tyre treads. A more effective way is to ensure that the road surface has adequate large-scale roughness, known as 'macrotexture'. A high macrotexture will also produce greater tyre deformation and hence increase the hysteresis component of friction. Macrotexture is usually expressed in terms of 'texture depth' and is commonly determined by the 'sand patch' test (described in Road Note 27 (51)) in which a known volume of fine sand is spread on the road surface so that the small valleys are filled up to the level of the peaks; the texture depth is the ratio of the volume of sand to the area covered. Texture depths on bituminous surfacings are typically in the range 0.5 to 2.5 mm. The rate at which skid resistance falls off with increasing speed is determined by the macrotexture (4). Figure 3.2 shows the percentage reduction in BFC between 50 and 130 km/h plotted against texture depth for a variety of bituminous surfacings. It will be seen that at a texture depth of 0.5 mm there is a reduction of about 30% and at 2.0 mm there is zero fall-off. On concrete surfaces the drainage channels are usually predominantly transverse rather than random and the drainage properties are somewhat different (4). A zero reduction in BFC between 50 and 130 km/h is achieved on a concrete surface with a texture depth of 0.8 mm.

It should be noted that at normal urban speeds the microtexture has a dominant influence on skid resistance and macrotexture is relatively unimportant. Ways of providing and maintaining good microtexture and macrotexture are discussed in Chapter 4.

3.3.2 Age of road surface.

Almost all new road surfaces have a high skid resistance because exposed aggregate particles have good microtexture and sharp edges. However, under the polishing action of vehicle tyres microtexture is reduced, the edges become worn and the skid resistance falls. Within about a year the skid resistance stabilises at an equilibrium level and thereafter only seasonal fluctuations occur, providing traffic remains constant and there is no structural deterioration of the surface. In practice it is often found that there is a reduction of texture depth with age due to coarse aggregate particles becoming embedded, abraded or detached from the surface.

3.3.3 Temperature.

The coefficient of friction between a tyre and the road surface is affected by temperature. The SFC of the surface will decrease by about 0.003 units per °C rise in tyre temperature (39). This is due mainly to the resilience of the tyre rubber increasing as the temperature increases. The viscosity of the water film will also be less at higher temperatures thereby reducing the friction coefficient but this effect is very small.

3.3.4 Seasonal variation.

There is a distinct seasonal pattern in skid resistance levels during the course of a year. Figure 3.3 shows the variation that was observed in the mean SFC of a group of 72 sections of road in London during 1976. The SFC fell from 0.47 in February to 0.33 in August and by December had recovered to 0.43 . A small part of the variation is attributable to temperature changes which affect the resilience of the test tyre but the variation is due mainly to seasonal changes in the microtexture of the aggregate particles in the road surface (40). Maclean and Shergold linked changes in skid resistance level with changes in the grading of detritus lying on the road (41). In the summer months, particularly during dry spells, the detritus is very fine and acts as a polishing agent but at other times it is coarser

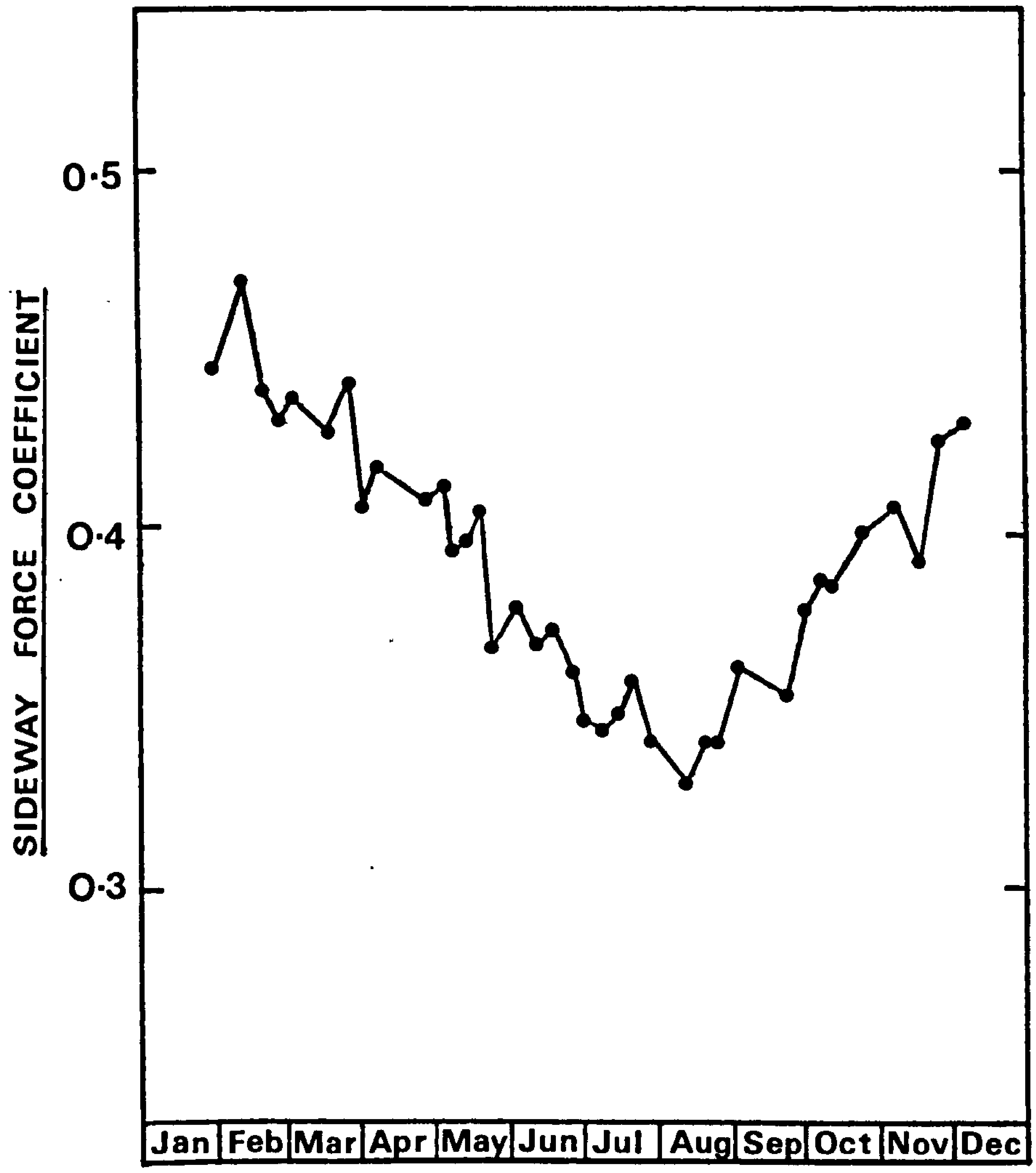


FIG. 3.3 Seasonal variation in SFC in London during 1976

and then has an abrasive rather than a polishing action. Natural weathering of the aggregate particles due to prolonged wetting and frost action also contributes to the improvement in microtexture during the winter months (40).

The TRRL has proposed (9) that for comparative purposes the mean summer SFC value should be used. This is the mean of at least three measurements spread over the period May to September (inclusive) in any one year. Mean summer values will vary from year to year depending on the weather conditions. For example, in the summer of 1959 there was very little rain and skid resistance levels were exceptionally low (39). The long-term mean summer SFC (i.e. averaged over several years) at a particular location is known as the Equilibrium Mean Summer SFC.

3.3.5 Traffic intensity.

The extent to which a road surface becomes polished is directly related to the intensity of the traffic. Consequently, a transverse profile of skid resistance will reveal lower levels in the wheeltracks and a longitudinal profile will show that levels are lower where there are additional stresses due to vehicles braking or turning (42). As might be expected, commercial vehicles have a greater polishing action than cars. Szatkowski and Hosking (8) demonstrated a highly significant correlation between commercial vehicle flow and equilibrium mean summer SFC for a standard surfacing at a number of sites in rural areas. This work is examined in more detail in Chapter 4 .

3.3.6 Aggregate properties.

Szatkowski and Hosking (8) have shown that for bituminous surfacings the PSV of the stone used for the chippings (or exposed coarse aggregate in the case of unchipped surfacings such as macadams) is the most important factor influencing the microtexture and hence the SFC. The very precise relationship which they were able to define between equilibrium mean summer SFC, aggregate PSV and traffic flow is discussed in Chapter 4. Aggregate abrasion resistance, size, shape and strength also influence microtexture and/or macrotexture and are discussed in Chapter 4.

In the case of concrete running surfaces the PSV of the coarse aggregate is much less important because about 88% of the upper surface consists of sand/cement mortar. The nature of the sand particles has a dominant effect on low-speed skid resistance. SFC values have been found to be higher when the sand granules are hard and angular.

3.4 MEASUREMENT OF SKID RESISTANCE

3.4.1 Test methods.

For many years the standard method of measuring wet-road skid resistance in Great Britain has been the sideway force method. It involves measuring the force generated at right angles to the plane of a vehicle-mounted test wheel set at 20° to the direction of travel. The wheel is fully slipping but is also free to rotate. The ratio of the sideway force to the vertical force on the test wheel is termed the Sideway Force Coefficient. The coefficient generated on a particular surface depends on a number of factors including the tyre rubber composition, tread pattern, degree of tyre wear and vehicle speed. In the SFC test the tyre is of a specified composition and is smooth, partly to represent the worst tyre condition but also to eliminate the effect of wear that would arise if a patterned tyre were used. The test can be performed at various speeds but it is customary to test at 50 km/h and unless otherwise stated this speed is assumed when SFC values are reported.

Other methods in use in Great Britain are the braking force, locked-wheel stopping distance and locked-wheel deceleration methods, and the TRRL portable skid resistance tester. The sideway force method has the great advantage that it gives a continuous measure of friction coefficient along the length of a road and, with present equipment, can be performed without interfering with the flow of traffic. The other tests give intermittent or point readings and involve closing the section of road to be tested.

The braking force method involves measuring the brake torque developed when the wheel of a smooth-tyred single-wheeled trailer is locked for two seconds on a wet road. The Braking Force Coefficient is the ratio of the braking force to the vertical force on the tyre. Measured BFC values are lower than SFC values measured at the same speed; the relationship

$$BFC = SFC \times 0.80$$

has been established (44). This is the standard method in the USA (using a patterned tread) and in some other countries but in Great Britain it is used mainly for research purposes. In some respects the braking force method is more appropriate for measuring skid resistance than the sideway force method because it simulates the locked wheel braking condition which is the most frequent skidding mode. One advantage of the method is that it can be used at high speeds (up to the capability of the towing vehicle). Its disadvantages are that it cannot be used on bends and it can produce only intermittent readings of skid resistance because, being a locked-wheel test, there are problems of the tyre overheating and experiencing excessive wear.

The stopping distance method most closely simulates the emergency braking situation. It involves locking all four wheels of a car at a predetermined speed and recording the stopping distance. It is clearly not suitable for the routine measurement of skid resistance but is frequently used by police officers investigating a skidding accident, using either the actual vehicle that had skidded in the accident or a similar vehicle, to estimate the mean friction coefficient. This information, together with measurements of skid marks, enables them to estimate the speed at which the vehicle had been travelling immediately before skidding.

The decelerometer method involves using a vehicle-mounted instrument to measure the deceleration rate when all four wheels of a test car are locked for one second at a standard speed (usually 50 km/h). The instrument may be either a simple device to measure the peak deceleration or a chart recorder producing a deceleration/time curve from which the mean locked-wheel deceleration may be found. The method is useful for comparing the friction performance of different tyres using the same vehicle but it is not suitable for routine skid resistance measurements.

The TRRL portable skid resistance tester measures the Skid Resistance Value, SRV, which is the coefficient of friction between the road surface and a spring-loaded rubber slider mounted on the end of a pendulum arm. It is a very simple device and has been widely used by highway engineers. Its principal disadvantage is that each test covers only a very small area of the road (about 0.01 m^2) and a large number of tests is necessary to obtain a representative value. The correlation between SRV and SFC is texture-dependent. It has been shown (45) that for medium and coarse-textured surfaces

$$SRV = SFC \times 105$$

On fine-textured surfaces the readings can be misleadingly high and on coarse-textured surfaces they are often erratic.

3.4.2 SCRIM.

The standard device for sideway force measurement in Great Britain is a test vehicle known as SCRIM (sideway force coefficient routine investigation machine) which is shown in Figures 3.4 and 3.5. It is a development of the machines which have been used by the TRRL (and its predecessors - the National Physical Laboratory and RRL) since about 1929. It was designed by the TRRL and provides, for the first time, a means by which a highway authority can monitor the skid resistance of its entire network and locate excessively slippery areas before they become skidding accident black spots.

The test wheel assembly is mounted on a frame within the wheelbase of a truck. It is subjected to a dead load of 200 kg and runs freely on vertical shafts so as to minimise the effects of vehicle chassis movements. The vertical plane of the test wheel is fixed at an angle of 20° to the line of the chassis. There is a mechanism for raising and lowering the wheel so that it is in contact with the road only when testing. When the vehicle is in motion with the test wheel lowered the wheel rotates freely. The 20° angle is sufficient to ensure that whilst rotating the wheel is also fully slipping and so generating the maximum sliding frictional force (Fig. 3.6). The smooth, pneumatic tyre is 76 x 500 mm in size (3.00 x 20 inches) and is of natural rubber of a specified resilience. Most SCRIM vehicles have a single test wheel on the nearside but the GLC

FIG. 3.4

SCRIM (sideway force coefficient routine investigation machine)

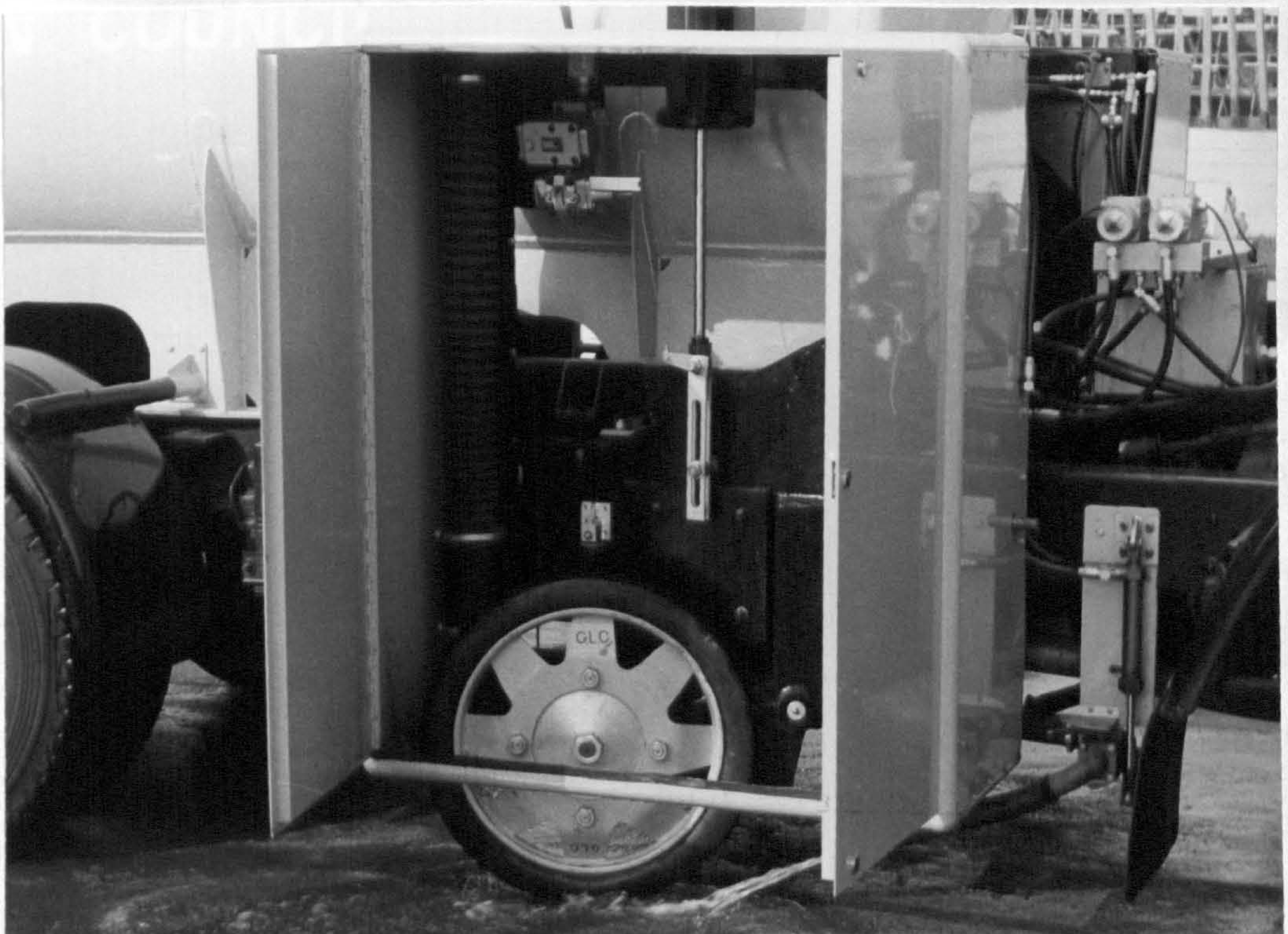


FIG. 3.5 SCRIM test wheel assembly

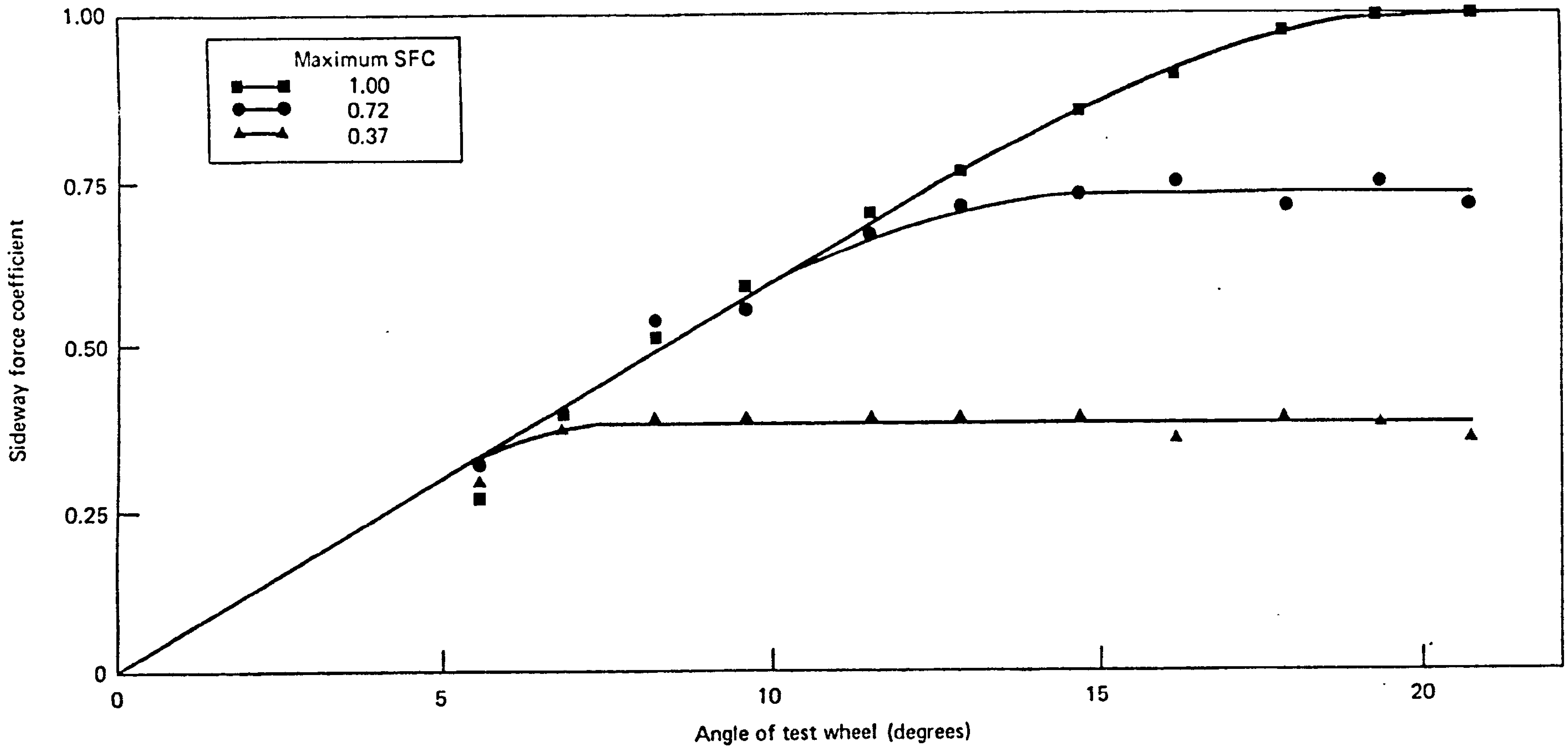


FIG. 3.6 Relationship between SFC and SCRIM test wheel angle (47)

SCRIM also has an offside test wheel. Comparative tests conducted by the GLC (results unpublished) have shown that the SFC in the offside wheel track is usually slightly lower than on the nearside and consequently all routine measurements in London are now made using the offside test wheel. The sideway force on the test wheel is measured by means of an electric load cell mounted behind the hub. The load cell output goes to a recorder in the vehicle cab. In calibrating the recorder it is assumed that the vertical force on the test wheel is constant and that the measured sideway force is, therefore, directly proportional to the SFC. A pulse transducer is fitted to the vehicle drive shaft to give a measure of the distance travelled. Every 5, 10 or 20 metres the mean values of skid resistance and speed are recorded on magnetic or punched tape. The recorder has facilities for inserting section reference numbers and event codes. A 2,750 litre tank is mounted on the vehicle so that a supply of water can be carried to wet the road surface immediately ahead of the test tyre. A tankful of water is sufficient for about 50 km of testing. SCRIM can be operated at up to 80 km/h under favourable conditions but the standard test speed is 50 km/h. The major advantages of the SCRIM vehicle are the very high test output and the fact that the tests can be conducted without interfering with the flow of traffic.

Although the principles of the SCRIM test method are the same as for the earlier SFC machines used at TRRL it has been found that the SFC values obtained with SCRIM are considerably higher (48). Furthermore, current SCRIM machines give higher readings than the prototype machine. TRRL recommend that, since most of their research work on materials and skidding accident risk was done using SFC values obtained with the early equipment, all SCRIM values should be adjusted to bring them into line with the earlier SFC measurements. This involves multiplying them by a factor which was obtained by examining all the readings obtained at the many TRRL full-scale road experiments in the years 1954 to 1976 and calculating an Annual Index of SFC. The mean index for the years 1963 to 1972 was used as a datum and the index for the years in which SCRIM machines of the current specification were used (1975 and 1976) was found to be 28% higher. Thus a factor of 0.78 is required. The factor has been the same for subsequent years up to the present but will not necessarily remain so in future years.

To avoid confusion the SCRIM users in Great Britain have agreed (50) that each SCRIM measurement should be multiplied by 100 so that it is expressed as an integer and then referred to as a 'SCRIM Reading' (SR). In this study it is also referred to as a 'SCRIM Value'. When a SCRIM reading is multiplied by 0.0078 it is known as a 'SCRIM Coefficient' and is equivalent to the SFC.

3.4.3 Variability of SCRIM measurements.

As with all measurements, there are errors associated with the measurement of skid resistance. It is important to identify the sources of these errors and to minimise them, or make allowance for them by applying corrections where appropriate. A further complication is that the quantity that is being measured is varying with time and this must be taken into account in defining a representative value for the skid resistance at a particular location. Many aspects of the problem have been investigated by TRRL and their findings have been presented in a series of reports relating to SCRIM measurements - LR737, LR738, LR739, SR346, SR642 (46, 39, 47, 48, 49). The annual correlation trials at Crowthorne in which all the available machines operating in the British Isles participate have formed an important component of the TRRL investigations into the operating characteristics of SCRIM.

3.4.3.1 Repeatability, k.

This may be defined as the random error associated with a single test-operator obtaining results using the same apparatus under constant testing conditions on identical samples. Quantitatively, it is that difference between two such single test results that would be exceeded in the long term in only one case in twenty in the normal and correct operation of the test. Mathematically, k is expressed by

$$k = 1.96\sqrt{2V_1}$$

where V_1 is the variance of the test differences.

To determine the repeatability of the GLC SCRIM which produced the skid resistance measurements used in the present study, duplicate tests were carried out on a group of 72 sites in London. The sites were each 100 metres in length and represented the range of surfacing types used on main roads in London. Preliminary tests were carried out to establish that the skid resistance was reasonably uniform within each section. To achieve conditions that were the same for the pairs of tests they were carried out after a period of heavy rain (to ensure that most of the detritus on the road surface was removed), during a period of a few hours on a cloudy day when air and road temperatures were constant. The road surface was dry before the first test and was allowed to dry out before the repeat test (to ensure a uniform water film thickness). The careful selection of the test conditions produced almost identical overall mean SCRIM values (46.85 for the first run and 46.75 for the repeat run). The variance of the differences was 1.2, giving a value of 3.0 for the repeatability of the GLC SCRIM. During the 1979 correlation trials at Crowthorne the repeatability of seven machines was assessed and an equivalent average value of 4.1 was obtained (49).

These results mean that if a 100 metre section of road is tested twice on the same day by the GLC machine the mean SCRIM values are unlikely to differ by more than 3 units. They also mean that if two sections of road are tested on the same occasion it may be assumed with 95% confidence that there is a real difference in skid resistance between them if the SCRIM values differ by more than 3 units.

3.4.3.2 Reproducibility, K.

This may be defined as the random error associated with test-operators obtaining results using different sets of apparatus under constant testing conditions on identical samples. Quantitatively, it is that difference between two such independent tests that would be exceeded in the long run in only one case in twenty in the normal and correct operation of the test. Mathematically, K is expressed by

$$K = 1.96 \times 2\sqrt{(V_1 + V_2)}$$

where V_1 is the repeatability variance and V_2 is the variance associated with the variability due to machine and operator differences.

During the 1979 TRRL correlation trials (49) seven machines were compared on standard sections of road and a mean of 2.9 was obtained for V_2 , giving a value of 9.1 for the reproducibility, K. Thus, differences of up to 9 units may be expected when a section of road is tested by two machines on the same occasion.

The repeatability value obtained for SCRIM is reassuringly low and confirms that the machine can satisfactorily fulfil its primary function of comparing skid resistance levels within a road network and locating sections which are relatively slippery. The fairly high reproducibility value indicates that care must be taken in interpreting test results obtained with different machines, particularly when they are to be compared with a target value.

3.4.3.3 Long-term machine variation.

The machine variation within a testing season must also be taken into account. In the repeatability assessment it may be assumed that the equipment remains constant because the replicate tests are conducted in quick succession but in normal testing there are several things that can change over a period of time, thereby increasing the test error.

(i) Calibration error. The measuring and recording system is calibrated by applying a series of known horizontal loads to the test wheel and adjusting the recorder to give the appropriate output readings (assuming that the vertical load on the test wheel remains constant). Calibration drift occurs and can be responsible for substantial errors if the equipment is not calibrated regularly. Daily checks on the calibration are recommended by the manufacturers. On some machines the load cell output is not quite linear. In such cases it is usual to ensure that the calibration is as accurate as possible in the 'critical' range 30 to 50, whilst accepting errors of up to 3 units outside this range. The linearity of the GLC SCRIM is very good up to a level of 80, beyond which the readings are about 2 units low.

(ii) Tyre wear. Wear on the test tyre has little effect on the readings providing the tyres are discarded when the 'tread' loss exceeds 3 mm (47). This degree of wear is reached after only about 500-700 km of testing and consequently most SCRIM machines use a number of tyres during a testing season.

(iii) Tyre differences. The test tyres are of a specified resilience (46 ± 3 percent rebound when tested by a Lupke resiliometer) and TRRL tests (47) have shown a range of 2 units in measured SCRIM value over the permitted resilience range (at SCRIM value 50). GLC tests have shown that there are real differences between test tyres, giving significant differences in measured SCRIM value of up to 6 units in tyres of the same nominal resilience. To eliminate the effect of tyre differences the usual GLC practice is to purchase a large batch of tyres (of the same nominal resilience) and to group them into sets giving similar measured SCRIM values; a single set of matched tyres is then used for a particular test season. This eliminates within-season tyre differences but does, of course, produce between-season differences.

3.4.3.4 Corrections to SCRIM readings

(i) Calibration correction. If the SCRIM calibration is known to be non-standard then individual readings may be adjusted accordingly. No such corrections were made to the SCRIM values used in this study because the only significant departure from non-linearity was at the top end of the range and was considered to be unimportant in the context in which the results were to be used.

(ii) Speed correction. The target test speed is 50 km/h but it is not always possible to achieve this, particularly on sharp bends or on roads where there are slow-moving vehicles. To establish a speed correction for the GLC SCRIM a group of sites representing the range of texture depths typically encountered in London was selected and at each site test runs were made at speeds from 10 km/h to 60 km/h (in random sequence). The relationship between speed and skid resistance is influenced by the macrotexture of the road surface (see 3.3.1) but for the relatively narrow range of texture depths investigated it was possible to establish satisfactory corrections for speeds in the range 30 to 50 km/h (see Table 3.1). Below 30 km/h the variation between sections was too great. Subsequent work by TRRL (47) produced correction values in close agreement with the GLC values. The SCRIM values used in this study were corrected for speed where necessary. Readings were rejected when they were at speeds below 30 km/h.

TABLE 3.1

SCRIM speed correction

TEST SPEED km/h	CORRECTION TO SCRIM VALUE
48-50	0
42-47	-1
38-41	-2
34-37	-3
31-33	-4
30	-5
below 30	reading rejected

(iii) Temperature correction. Although a temperature correction can, in principle, be applied to SCRIM readings (see 3.3.3) it is not usual to do so in routine testing. Variation due to temperature changes is usually considered to be part of the seasonal variation and is dealt with accordingly.

(iv) Seasonal correction. The TRRL (8) recommend that at least three SCRIM measurements should be obtained in any one year, spread out over the testing season (May to September inclusive) to give a mean summer value. Although this is highly desirable it is rarely possible to achieve and most highway authorities opt for a single test run, with the results adjusted to give an estimated mean summer value.

As a basis for adjusting the test results to compensate for seasonal variation some authorities make use of the curve published by TRRL (39) showing long-term average monthly skid resistance values. This is to be deprecated because in individual years there can be very large departures from the average values. For example, in the period 1958-68 the average index of skid resistance in May was 95.5 but it ranged from 83 (in 1959) to 105 (in 1963). In the GLC area the normal practice for routine monitoring of skid resistance is to make a single test run each year on all the Principal roads and to use data from a control section to provide a seasonal correction factor. The control section is close to the SCRIM garage and is tested at the start and end of each testing shift. At the end of the testing season all the control section results are combined and a mean summer value for the section is calculated; the mean control section value for each shift is then calculated and subtracted from the mean summer value; the result gives the seasonal correction value which is then added to the individual readings obtained in the shift to give estimated mean summer values.

(v) Tracking correction. Since the skid resistance varies transversely across the road, with the lowest levels occurring in the wheeltracks, it is most important that the test wheel path is along the most heavily-trafficked track. Any deviation will lead to misleadingly high values being recorded. Investigations by GLC have shown that in areas where traffic is canalised deviations of only 0.5 metres from the wheeltrack have produced SCRIM values up to 20 units higher than those obtained in the correct track. Great reliance is placed on the judgement of the driver and/or operator in selecting and traversing the correct track. It is, unfortunately, not possible to apply a correction for tracking error, but where the vehicle is forced to deviate from the target track it is customary for the readings to be flagged as being suspect.

(vi) Bend correction. There are two additional potential sources of error when the SCRIM vehicle travels round a bend whilst testing. Firstly, the effective angle of the plane of the test wheel relative to the direction of travel will depart slightly from the normal 20°. For example on a 50 m radius bend the change in effective angle is about 3°. Figure 3.6 shows that an increase of 3° in the angle would have no effect because at 20° the maximum sideway force is already being generated. The effect of a decrease of 3° in the angle depends upon the SFC level of the road surface. Up to SFC 0.85 there would be no effect but above that level the sideway force would be reduced; at SFC 1.0 the recorded skid resistance would be 4% low. Thus, even on a very low radius bend the effect of the change in wheel angle is very small. A more important effect arises from the variation in vertical load on the test wheel as the vehicle travels round a bend. The action of the damping device on the test wheel suspension (together with friction in the bearings of the vertical shafts of the test wheel assembly) causes the effective load on the wheel to decrease on a left-hand bend, with a consequent decrease in recorded skid resistance, and vice-versa on a right-hand bend. (The opposite is true of the GLC SCRIM when the offside test wheel is used). A correction factor has not yet been formulated for bends but the problem is currently being investigated by some of the SCRIM users.

(vii) SFC Index correction. After applying any necessary corrections the SCRIM readings are converted to equivalent SFC values by multiplying by the factor 0.0078 (see 3.4.2).

3.4.4 Summary.

This examination of the use of the SCRIM vehicle has highlighted some of the difficulties associated with the measurement of road surface skid resistance.

The different test methods all give different results although they are all apparently measuring the same quantity, i.e. the dynamic coefficient of friction of the wet road surface. For any of the test methods minor variations in the equipment or the operating procedures can lead to major differences in test results. It is, therefore, necessary to consider the tests as being empirical and to carefully standardise the equipment and procedures.

The greatest problem arises from the fact that the quantity that is being measured is itself varying with time and hence it is difficult to decide what constitutes a representative value for a given section of road. The TRRL suggest taking the mean of at least three measurements spread out over the summer months. This would help to some extent but most highway authorities find it as much as they can do to perform a single monitoring survey each year on their main road network.

The SCRIM test vehicle has proved to be the most practicable device for the routine measurement of skid resistance. The test repeatability is good (4 units) but the reproducibility is high (9 units). This indicates that SCRIM is a very good tool for monitoring a road network to locate areas which are relatively slippery but is not entirely satisfactory for establishing 'absolute' SFC values which can be compared with target values. Nevertheless, it is the best available device for performing routine skid resistance tests on public roads. It is now well established in Britain and several other countries and it is likely that further refinements in the equipment and the operating procedures will lead to improvements in the test precision.

CHAPTER 4

ROAD SURFACE CHARACTERISTICS AND SURFACING MATERIALS

4.1 SURFACE TEXTURE

In order to provide good wet-road skid resistance over a range of speeds a road surface must have good microtexture and adequate macrotexture. It is also desirable that the surface should be durable and economical, and give a smooth, quiet ride with low tyre wear. Some of these requirements may, of course, be mutually conflicting.

The small-scale asperities on the aggregate particles exposed at the road surface form the microtexture which is necessary for the tyre to penetrate thin water films and achieve dry contact with the road. This is a basic requirement for the generation of the maximum frictional force at the tyre/road interface and microtexture is, therefore, important at all vehicle speeds. At urban speeds it is the dominant factor controlling skid resistance.

Macrotexture - formed by the large-scale asperities on the surface - is necessary for the dispersal of bulk water at higher speeds and, additionally, it induces greater tyre tread deformation and hence increases energy losses due to hysteresis. Macrotexture influences the extent by which the skid resistance falls with increasing vehicle speed (see 3.3.1). It is generally considered to be relatively unimportant at urban speeds. The Department of Transport specification for bituminous surfacings on new roads (11) has a minimum texture depth requirement only for high-speed roads (defined as those roads where some vehicles travel above 60 mile/h (95 km/h)). For such roads a minimum initial texture depth of 1.5 mm is required. No maintenance intervention level for texture depth has been defined by the DTp but TRRL (9) have suggested a minimum value of 1.0 mm for high-speed roads. It would, perhaps, be unwise to ignore macrotexture completely on urban roads because, although they are subject to speed limits of 30 or 40 mile/h, many sections of road can be identified where some vehicles travel at speeds well in excess of the speed limit and consideration should be given to providing sufficient macrotexture to limit the reduction in effective skid resistance at higher speeds.

Microtexture and macrotexture may be produced either by incorporating the required characteristics into the upper structural layer of the road (i.e. the bituminous wearing course or, in the case of a concrete road, the top of the slab) or by some form of surface treatment such as surface dressing.

The most widely used wearing course mixture on main roads in Great Britain is hot-rolled asphalt, in which the texture (both microtexture and macrotexture) is provided by crushed rock chippings which are rolled into the top of the surfacing. In other wearing course materials, such as bitumen macadams, the texture is provided by the coarse aggregate in the mix. In the case of concrete running surfaces, which are relatively rare on urban main roads in Great Britain, the microtexture is provided by the fine aggregate in the mix and the macrotexture is produced by brushing and/or cutting grooves in the freshly-laid concrete. The most common form of surface treatment is conventional surface dressing in which a thin film of binder is sprayed on to an existing surfacing and then covered with a single layer of chippings. Other forms of surface treatment involve premixing the binder and aggregates before spreading them on the road. All of these materials and processes are examined in sections 4.5 to 4.7.

The microtexture of the chippings or other exposed aggregate particles is reduced by the polishing action of vehicle tyres. It is important to ensure that the polish resistance of the stone (measured by the PSV test) is sufficient in relation to the frictional demand and traffic intensity at any individual site. Macrotexture is lost if chippings are detached from the surface, become excessively embedded or are abraded away. In the case of concrete the microtexture is reduced when the edges of the fine sand particles become worn and macrotexture is reduced by the wearing away of the surface mortar.

4.2 ROLLING RESISTANCE, TYRE NOISE, SPRAY, LIGHT REFLECTION, TYRE WEAR

4.2.1 Introduction.

Although surface texture is primarily of importance in relation to skid resistance it does also influence other aspects of the performance of road surfacings. It is, therefore, important that, in designing a texture for good skid resistance and in selecting the materials, the possible effect on the other characteristics should be considered.

4.2.2 Rolling resistance.

When a tyre is rolling freely along a road surface each element of the tread is deformed as it meets the surface and recovers as it leaves. Energy is expended in deforming the tyre and, because of hysteresis effects, is only partially recovered when the tyre recovers; the lost energy appears as heat in the tyre. The consequent retarding effect - the rolling resistance - is equivalent to a coefficient of friction of the order 0.01 to 0.03 for car tyres (53, 54) depending on the macrotexture of the road surface and the tyre properties. For most types of surfacing (but not pervious macadams) the rolling resistance will increase with increasing texture depth. Thus, a higher texture depth will lead to greater fuel consumption.

4.2.3 Tyre noise.

With large numbers of people living or working in close proximity to main roads it is particularly important in urban areas to consider traffic noise implications. At urban traffic speeds engine noise is the most important component of vehicle noise but noise generated at the tyre/road interface does contribute to the overall level and is influenced by the macrotexture of the road surface. TRRL studies (55) have shown that car tyre noise on dry roads increases with increasing texture depth for most types of surfacing. Therefore, unnecessarily high texture depths should be avoided in densely populated areas.

Walker and Oakes (56) have demonstrated that the spacing of the coarse aggregate particles at the surface of the road can influence perceived noise levels. On Delugrip-type surfaces (described in Section 4.5.3) they found that the shorter aggregate spacing (compared with hot-rolled asphalt) produced peak noise levels which were in the less-sensitive higher-frequency band of the noise spectrum and were perceptibly quieter.

Tyre noise is greatly increased on most road surfaces in wet conditions. However, on pervious macadams (friction courses) most of the water drains through the uppermost layer of surfacing instead of lying on the surface and there is little or no difference in noise level between wet and dry conditions. Pervious macadams are also quieter in the dry than other surfacings of equivalent skid resistance because of the high acoustic absorption in the surface voids (57).

4.2.4 Spray.

On motorways and other high-speed roads the impairment of visibility in wet weather due to spray thrown up by vehicle tyres constitutes a major hazard. The spray can be reduced by increasing the texture depth, especially if the resulting macrotexture is such that the surface voids are all interconnected so that water can be expelled horizontally from the tyre/road contact area without the development of very high fluid pressures. In urban areas splashing of ponded water is more of a problem than spray but is, of course, the consequence of an unsatisfactory road profile rather than inadequate macrotexture. Pervious macadams can be very effective in reducing both splash and spray.

4.2.5 Light reflection.

Urban street lighting in Great Britain is designed so that at night unlit objects in the carriageway are seen in silhouette against the light background of the road surface. The luminance of the surface needs to be as uniform as possible. Sabey and Walker (58) have shown that this can best be achieved by providing a surface which has good microtexture and coarse macrotexture. If the texture is inadequate there will be streaky reflections and glare from the street lights and oncoming headlights when the road is wet.

4.2.6 Tyre wear.

TRRL studies (59) have shown that road surface microtexture is a major factor determining tyre tread wear, with macrotexture having a relatively small influence. Increasing microtexture levels, and hence skid resistance levels, will therefore result in increased tyre wear. For localised skid resistance improvements the additional tyre wear costs are thought to be small in relation to the saving in accident costs but where there are extensive improvements in skid resistance the additional tyre wear costs could be a significant disbenefit (see Chapter 9).

4.3 AGGREGATES FOR BITUMINOUS SURFACINGS

4.3.1 Introduction.

Britain is fortunate in having a very wide range of naturally-occurring mineral aggregates within its relatively small geographical area. Investigations have been carried out at the TRRL over many years to identify the most important qualities of an aggregate in relation to its durability and skid resistance performance. Tests have been developed to measure these qualities and are now incorporated into British Standards. The important qualities of an aggregate are its resistance to polishing, abrasive wear, crushing and natural weathering. It must also be available in sufficient quantity - preferably at a reasonable price.

4.3.2 Polish resistance.

The relative polish resistance of an aggregate is measured by the Polished Stone Value (PSV) test which is described in BS 812 (10). Aggregate particles 8-10 mm in size are embedded in a setting compound and subjected to simulated trafficking in an accelerated polishing machine using fine emery as a polishing agent. The degree of polish is assessed by measuring the coefficient of friction between the test specimen and a standard rubber using the TRRL portable skid resistance tester. The PSV is the coefficient of friction multiplied by 100.

The accelerated polishing test was developed for research purposes by Maclean and Shergold (41) in the mid-1950's. The test value obtained was originally called the Polished Stone Coefficient, PSC. Later improvements to the test produced slightly lower results and on adoption as a British Standard test the name was changed to Polished Stone Value with the results being expressed as integers to distinguish them from values obtained with the original test. Prior to the introduction of the accelerated polishing test the selection of aggregates for use as roadstones was somewhat haphazard. In general, local materials were used, with abrasion-resistant stones being preferred because they were more durable. Unfortunately, in many cases they also had poor resistance to polishing. The use of the accelerated polishing test led to the exclusion of the poor aggregates and to the identification and increased use of those with good resistance to polishing. In developing the test Maclean and Shergold found that there was a very good correlation between PSC and SFC at a small number of experimental sites on heavily-trafficked roads where a range of roadstones had been used. This established the value of the test in ranking roadstones in order of merit but was mistakenly interpreted by many people as meaning that for any particular roadstone the skid resistance on the road would be the same value as the PSC, regardless of traffic intensity. Even the 1969 edition of the Department of the Environment Specification for Road and Bridge Works (60) specified minimum PSV's without regard to traffic intensity. It simply required a minimum of 62 at 'difficult' sites and 59 at 'average' sites. Not until 1976 was the trunk road specification altered to take into account Szatkowski and Hosking's findings on the relationship between SFC, PSV and traffic flow. DTp Technical Memorandum H.16/76 (Specification requirements for aggregate properties and texture depth for bituminous surfacings to new roads) (11) specifies minimum PSV's ranging from 45 to 75 depending on the site category and the traffic loading.

4.3.3 Abrasion resistance.

Macrotexture (and ultimately microtexture) will be lost if an aggregate wears too rapidly under the grinding action of vehicle tyres. Resistance to abrasive wear under traffic is measured by the Aggregate Abrasion Value (AAV) test (described in BS 812) in which 14 mm particles of the aggregate are embedded in a setting compound and subjected to a standard abrasion procedure using silica sand as the abrasive. The AAV is the percentage loss in mass of the aggregate. The DTp specification (11) permits a maximum AAV of 10 for chippings on heavily trafficked roads and 12 for the coarse aggregate in macadams.

4.3.4 Resistance to natural weathering.

Disintegration of road aggregates due to chemical weathering or the action of frost is extremely rare in Great Britain. Consequently, no tests for 'soundness' appear in British specifications for wearing course aggregates. Hosking and Tubey (70) investigated a number of possible tests for soundness and concluded that no really satisfactory test has yet been devised. Shergold (61) has demonstrated that only natural aggregates with a high water absorption value (in excess of 1.5%) are likely to be frost-susceptible. Hartley (62) has identified a number of rock types (e.g. certain dolerites) which are unsuitable as roadstones because some of the constituent minerals are dissolved or chemically altered when in contact with water.

4.3.5 Strength.

Wearing course aggregates must be sufficiently strong to withstand the stresses induced during laying and compaction as well as in subsequent trafficking. Various tests for strength have been devised and are described in BS 812 (Aggregate Crushing Value, Aggregate Impact Value, Ten Percent Fines) but, in general, aggregates which have good abrasion resistance also have adequate strength and requirements for minimum strength rarely appear in British specifications.

4.3.6 Size and Shape.

The size of the chippings or exposed coarse aggregate particles in bituminous surfacings has an effect on skid resistance. Hosking (43) has shown that halving the size of aggregates used as chippings (within the range 3 mm to 25 mm nominal size) increases the SFC by about 0.08 units, providing adequate texture depth is maintained. This effect is presumably due to the fact that the smaller aggregate particles present more edges per unit area of surfacing thus increasing the real area of contact between the tyre and the road. It would, therefore, appear to be advantageous to use as small a chipping as possible. However, in practice it is found that in hot-rolled asphalt it is difficult to retain chippings smaller than 14 mm in size, and in surface dressings laid on bituminous surfacings excessive embedment with consequent loss of texture depth is likely at sizes below 6 mm. In the case of surface dressings laid on concrete embedding of chippings is not a problem (because the surface is rigid) but the chippings must be sufficiently large to prevent excessive loss of texture due to abrasive wear. Chippings for hot-rolled asphalt are normally either 20 or 14 mm and for surface dressing 6, 10 or 14 mm. With macadams the size effect is somewhat less; halving the size of the coarse aggregate increases the SFC by about 0.03 units. The maximum size of the coarse aggregate fraction in wearing course macadams ranges from 6 to 20 mm.

Aggregate particles that are flaky are undesirable at the road surface. They are more likely to fracture under traffic and, when used as chippings, are less firmly embedded in the substrate and hence more likely to become detached. Flaky chippings also give a lower texture depth than particles which are more cubical, because they tend to lie flat on the road surface. BS 812 defines a particle as being flaky if its thickness (smallest dimension) is less than three-fifths of its nominal size. The Flakiness Index is the percentage by weight of flaky particles of size equal to or greater than 6.3 mm. BS 63 (63) specifies a maximum flakiness index of 35 for chippings and BS 594 (64) requires that on high-speed roads and at hazard sites the flakiness index should be less than 25.

4.3.7 Availability of durable, high-PSV aggregates.

Britain is well endowed with materials suitable for use as roadstones. In BS 812 (1975) the various materials are classified into eleven groups (artificial, basalt, flint, gabbro, granite, gritstone, hornfels, limestone, porphyry, quartzite, schist), the members of each natural rock group being broadly similar to others in the same group in petrographical characteristics. Figure 4.1 shows the range of values of PSV within each group (except for the schists, which are unsuitable as roadstones). It will be seen that the gritstones give the highest PSV's and the flints and (with a few exceptions) the limestones the lowest. The gritstones have a high polish resistance by virtue of the fact that they consist of a conglomeration of hard mineral grains set in a soft matrix. Under trafficking mineral grains are plucked from the surface of the aggregate, exposing unpolished grains. Because of this wear mechanism many gritstones which have a high PSV are unsuitable as roadstones. A survey by Hawkes and Hosking (65) has shown that there are substantial reserves of durable, polish-resistant aggregate. They examined samples of gritstone (and similar rocks) from 86 locations in the United Kingdom and found that 23 had a PSV of between 65 and 72 with AAV of 10 or less. A further 17 had a PSV of 60-64 and AAV of 10 or less. The best samples came from Wales but good material was also found in Salop, Devon, Cornwall, South Scotland and Northern Ireland. Although there are abundant reserves of good quality roadstones they are unevenly distributed and many areas where there is a high demand for them are a considerable distance away from suitable sources. In south-eastern Britain, for instance, the roads are very intensively trafficked but the only local aggregates are flint gravels which have very poor resistance to polishing. In areas where the local materials are poor it is obviously necessary to import suitable materials from elsewhere.

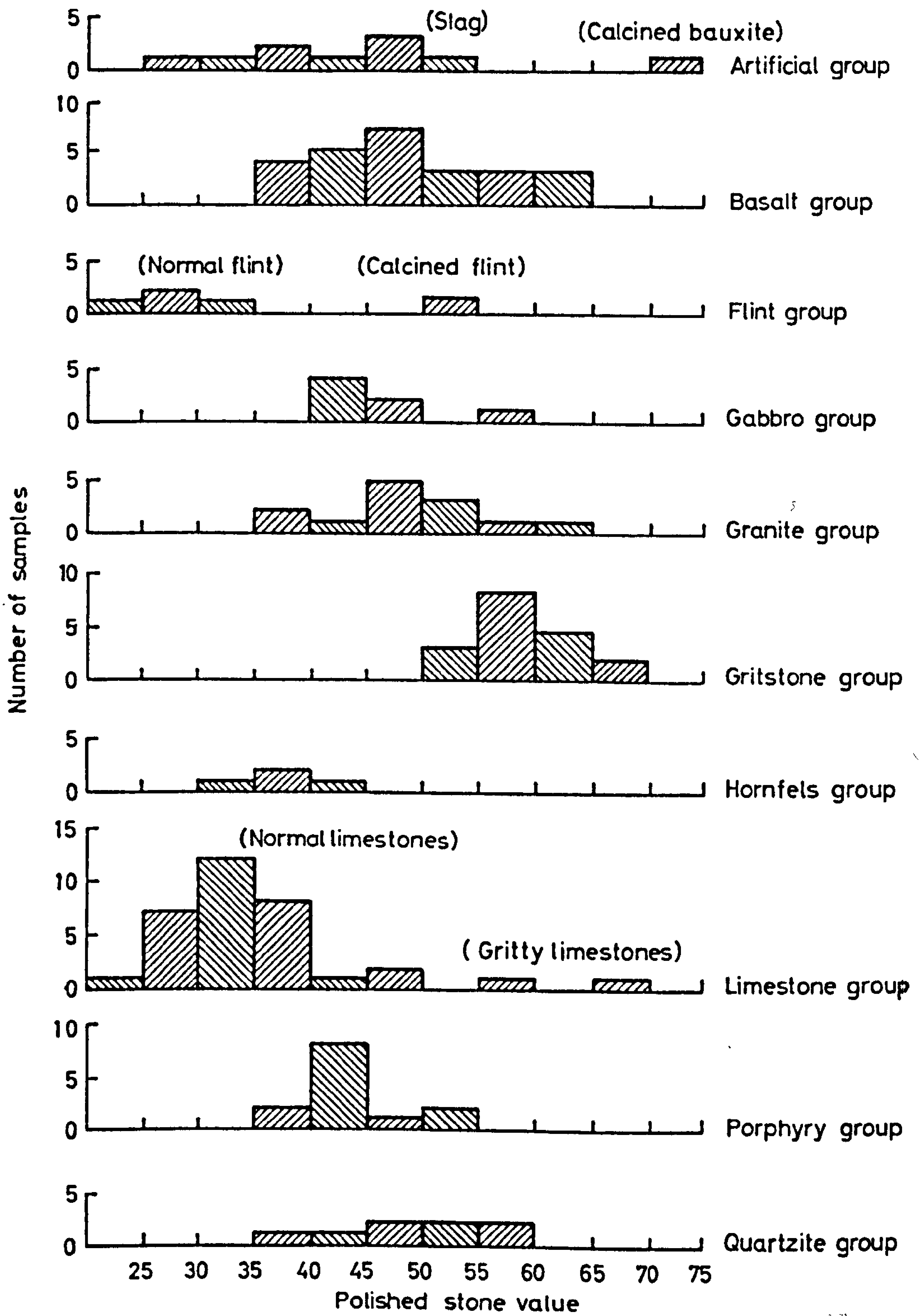


FIG. 4.1

Distribution of Polished Stone Values in different groups of rock (89)

Inevitably, haulage costs are then higher and form a high proportion of the overall price of the aggregate. This does mean that in percentage terms the price differential between very good and moderately good aggregates is then relatively low and many highway authorities will opt for the top quality aggregates in view of the small additional cost. In areas where the local materials are only moderately good the decision to import better quality aggregates is more difficult because the additional costs will be much higher proportionately and there may also be objections from local political or commercial groups.

Included in Figure 4.1 in the artificial group is calcined bauxite which is not indigenous but is imported from Guyana and certain other countries. It is exceptionally durable and polish-resistant. Trials in London (66) have shown that the best type is the RASC grade from Guyana which has a PSV of 75 and an AAV of only 2. It is extremely expensive (about 20 times the price of natural roadstones) and its use has been confined to special surface treatments (e.g. Shellgrip) which are used at accident black spots on heavily-trafficked roads. Supplies of good-quality calcined bauxite in roadstone sizes are in very short supply. Attempts have been made to produce commercially-viable synthetic high-PSV aggregates (66) but they have all failed because the resultant materials have proved to be either too expensive or insufficiently durable.

4.4 RELATIONSHIP BETWEEN SFC, PSV AND TRAFFIC

4.4.1 Introduction.

Szatkowski and Hosking of TRRL demonstrated that the equilibrium mean summer SFC of a chipped hot-rolled asphalt surfacing or a surface dressing can be predicted from a knowledge of the PSV of the chippings and the traffic intensity (expressed in terms of commercial vehicles per lane per day). Their work is described in detail in TRRL Report LR504 (8) which was published in 1972. Using data from a large number of sites they performed a multiple regression analysis and obtained the equation

$$S = 2.4 \times 10^{-2} - 6.63\, t \times 10^{-5} + p \times 10^{-2} \qquad \underline{A}$$

where S = equilibrium mean summer SFC

t = commercial vehicles per lane per day

p = aggregate polished stone value

The correlation coefficient was 0.91 for 139 sets of observations (highly significant statistically).

This finding was very important because it provided a rational basis for specifying the aggregate PSV required at an individual site to achieve a target SFC. Equation A is valid only for rolling traffic. Later work by Hosking and Tubey (42) showed that where traffic was braking or turning there was additional polishing and the PSV required to achieve a specified SFC was at least five units higher than indicated by equation A. The relationship defined by equation A was obtained using data only from rural sites and has not yet been validated for urban conditions. Accordingly, as part of this study a survey was conducted to compare the actual SFC of hot-rolled asphalt on Principal roads in London with the SFC predicted from equation A.

4.4.2 Site selection.

The sites included in the survey were all on Principal roads in London, i.e. roads whose maintenance is the responsibility of the GLC. The aim was to obtain a group of sites with a range of traffic flows and aggregate PSV's. Several routes were examined in each of seven representative boroughs (Lambeth, Southwark, Wandsworth, Merton, Ealing, Hounslow, Tower Hamlets). Sections 50 to 100 metres in length were sought, meeting the following conditions :-

1. Surfaced with hot-rolled asphalt to BS 594 (64).
2. Surfacing uniform within section length and structurally sound.
3. Surfacing at least three years old (to ensure that the initial polishing phase was complete and the equilibrium SFC level had been reached).
4. Chipping rate of spread average or better.
5. Known chipping source.

6. Path taken by commercial vehicles well defined.
7. Traffic flow and braking pattern uniform within section length.
8. Straight road.

Sixty-five suitable sections of road were identified; details of the sites are given in Appendix C.

4.4.3 Site data.

At each site a note was made of the location, chipping type, PSV of chippings, SFC and commercial vehicle flow.

(i) Location. The precise location of each section was established in terms of the link reference and the distance along the link.

(ii) Chipping type.

The source of the roadstone was noted. Records of roadstones used at individual sites are rare in London and it was necessary to rely mainly on visual identification. Sites were discarded where the roadstone could not be identified positively; the only exception being at a few sites where it was known that the stone was either from Gore quarry or Craig-yr-Hesg quarry. Stones from these two sources are visually indistinguishable to a non-specialist but since they have the same PSV it is not necessary to differentiate between them.

(iii) Aggregate PSV.

Polished Stone Value test results were obtained from the GLC Testing Station, a number of county highways laboratories and the TRRL. The mean values from these sources are given below.

Bardon Hill	-	59
Castle-an-Dinas	-	55
Craig-yr-Hesg	-	67
Criggion	-	60
Dean	-	52
Enderby	-	50
Furnace	-	45
Gore	-	67
Tuttle Hill	-	57

(iv) Sideway force coefficient.

SFC readings were extracted from the 1984 routine SCRIM survey, each reading having been adjusted (following comparison of the grand mean value for each borough with mean values for earlier years) to give an Estimated Equilibrium Mean Summer SFC Value.

(v) Traffic flow.

Estimates were made of the number of commercial vehicles per day in the SCRIM test path at each site (normally the offside wheel track in the nearside lane) using GLC Traffic Survey Section data on total vehicle flow in each link and proportion of commercial vehicles in the locality.

4.4.4 Data analysis.

Much of the statistical analysis in this and later chapters was carried out using the SPSS suite of computer programs (Statistical Package for the Social Sciences (109)) which includes procedures for correlation, regression (simple and multiple), analysis of variance and data plotting.

The SFC predicted from Equation A was calculated for each site using the aggregate PSV and the commercial vehicle flow values. Predicted SFC values are shown plotted against actual values in Figure 4.2. At a high proportion of sites the actual SFC is substantially lower than the predicted value, the mean SFC difference being 0.11 with standard error (s.e.) 0.008).

A multiple linear regression analysis performed using the SPSS REGRESSION procedure, with SFC as the dependent variable and PSV and traffic flow as predictor variables, produced the regression equation shown below.

$$S = 0.810\, p \times 10^{-2} - 1.293\, t \times 10^{-5} - 0.083 \qquad \underline{B}$$

$r = 0.743$

$r^2 = 0.552$

s.e.(overall) = 0.0445

s.e. (S) = 0.00094

s.e. (t) = 0.00670

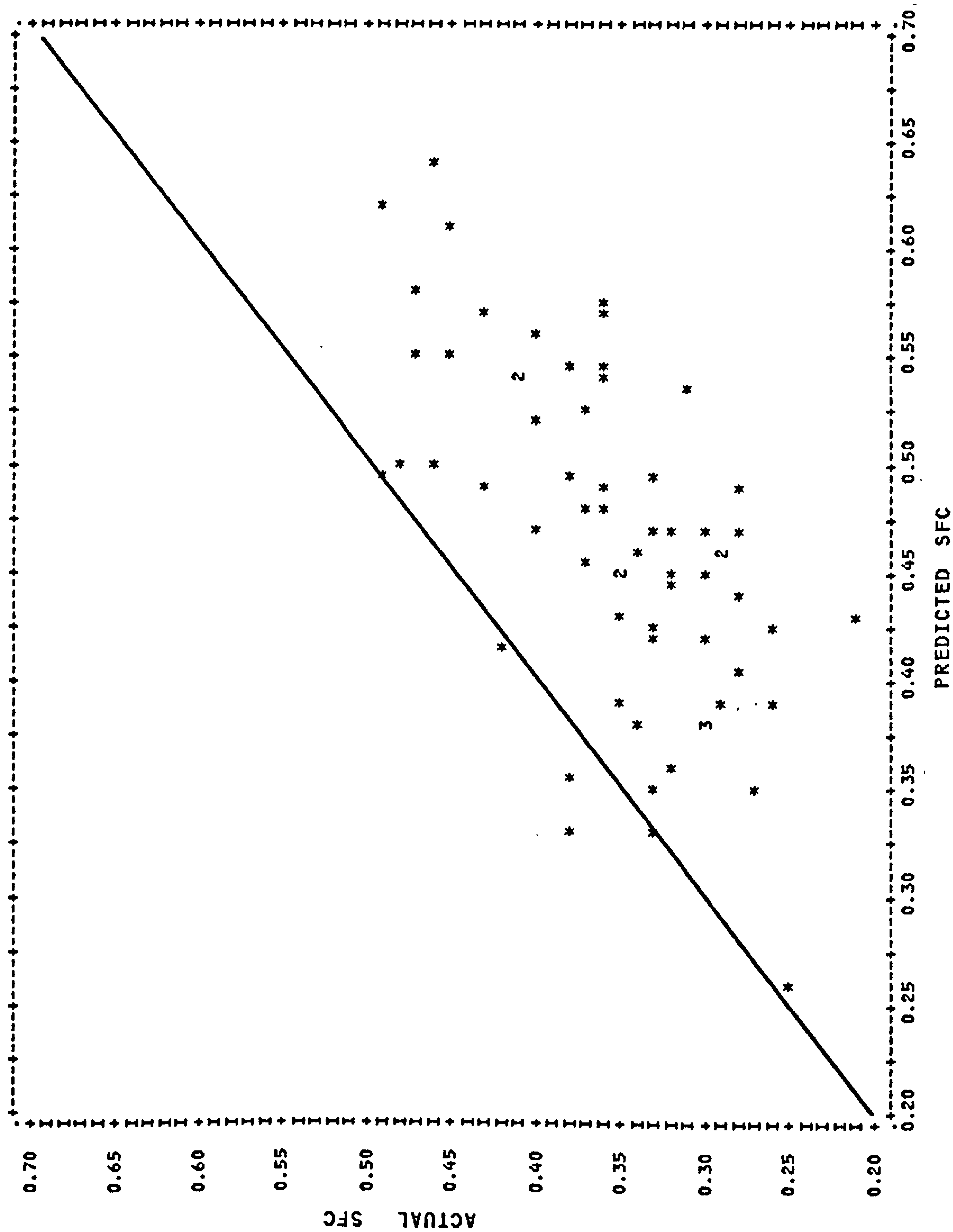


FIG. 4.2 Actual SFC v. SFC predicted from regression equation in LR 504

The correlation coefficient, r, is a measure of the degree of linear association between SFC and the two independent variables (acting jointly). The r value of 0.743 indicates a high degree of correlation (significant at probability better than 0.01). The r^2 value of 0.552 indicates that PSV and traffic flow together explain 55% of the variation in SFC.

Comparing Equations A and B it will be seen that regression coefficients are similar for the SFC term (0.01 compared with 0.0081) but for the traffic term the coefficient is much lower in Equation B (0.0000129 compared with 0.0000663). This suggests that the influence of traffic intensity on SFC is smaller on roads in London compared with the rural roads for which Equation A was derived. It must, however, be noted that the confidence limits about the coefficients in Equation B are very wide. The 95% confidence interval (± 1.96 x standard error) is 0.0063 to 0.0099 for the PSV term and -0.0000002 to 0.0000261 (i.e. not quite significant at 0.05 probability) for the traffic term. It is clear that the LR504 equation is unsatisfactory for predicting urban SFC levels but further work would be necessary to establish a reliable alternative equation for urban use. Any future investigation should also establish the reasons for the lower SFC levels on urban roads. Possible reasons are :-

1. Rates of spread of chippings tend to be lower on urban roads.
2. Traffic speeds are much lower on urban roads and there is more braking.
3. The pattern of commercial vehicle axle loads has changed in recent years.

BS 594 requires that on high-speed roads and at hazard sites the rate of spread of chippings should be the maximum practical rate consistent with permanent retention of the chippings in the asphalt. It gives a guide to the target rate of spread based on the nominal size, percentage undersize and flakiness of the chippings. A typical target rate of spread for 20 mm chippings is 11.5 kg/m². Ideally the chippings should cover 100% of the surface area but it is recognised that this is impracticable and the target rate is equivalent to a coverage of about 70%. For other roads it is suggested that the target rate may be reduced by 1.5 kg/m² (for 20 mm chippings). This would give just over 60% coverage. Observations on roads in London suggest that rates of spread are such that coverage is typically 55-60%. This lower rate of spread is due partly to the target rate being lower but is also a consequence of lower standards of workmanship on urban roads resulting from the difficult operating conditions. The relationships developed in LR504 were based on observations from selected rural sites where the wearing course was densely chipped. It is to be expected that a lower chipping rate will result in a lower SFC since there will be a higher proportion of asphalt matrix (with inferior microtexture) at the running surface.

The LR504 sites were all at rural locations where the traffic was flowing freely. On urban main roads the frequency of braking and accelerating is greater and this will lead to greater polishing stresses. Vehicle speeds are generally much lower on urban roads and it is possible that increased tyre/road contact times increase the polishing effect.

There have been substantial changes in the pattern of commercial vehicle axle loading since the period in which the LR504 observations were made (110). The number of vehicles operating with axle loads close to the legal limit (10 tonnes) has increased and these vehicles have a disproportionately high damaging effect on the road structure. The average number of axles per commercial vehicle has increased, as has the damaging power of the average commercial vehicle. It is probable that the polishing effect has increased correspondingly.

4.5 WEARING COURSE SURFACINGS FOR HEAVILY-TRAFFICKED URBAN ROADS

4.5.1 Introduction.

A wearing course surfacing for use on heavily-trafficked urban roads must be durable and provide adequate skid resistance. It must also have good load-spreading properties, be resistant to deformation and given an acceptable ride. A long service life is particularly important on urban main roads because of the disruptive effect of resurfacing operations. Delays to traffic can be costly and the work invariably causes a nuisance to local residents. Additional costs in urban areas arise from the need to carry out much of the work at night or at weekends to minimise traffic delays and also from the need either to remove the existing wearing course or raise the level of footways, kerbs and ironwork (gulley gratings, manhole covers, etc.) to accommodate the additional thickness of surfacing. The cost of the actual surfacing material may be only a small proportion of the overall cost of resurfacing and this means that an expensive long-life material is often more cost-effective than a cheap material that would need to be replaced more frequently. Dense impermeable surfacings (e.g. hot-rolled asphalt, mastic asphalt) are much more durable than the more open-textured materials (e.g. open-textured and medium-textured macadams).

The predominant wearing course surfacing for heavily-trafficked roads in Great Britain is hot-rolled asphalt (described in section 4.5.2) to BS 594. Mastic asphalt (to BS 1447) (69) is even more durable than hot-rolled asphalt but it is more expensive and difficult to lay and its use is confined mainly to special locations such as bus stops and bridge decks. A proprietary material known as Delugrip has been used successfully in London and elsewhere and is described in Section 4.5.3. It is similar to a dense bitumen macadam but is carefully designed to give good skid resistance and high stability under heavy traffic. Much interest has been shown in recent years in the use of pervious macadam surfacings (friction courses) as a drainage layer to rapidly remove free surface water and so reduce splash and spray. They have been used mainly on high speed roads but trials in London (described in Section 4.5.4) suggest that they could be useful as skid-resistant surfacings on urban roads, superimposed on an existing wearing course.

The more open-textured wearing course macadams (to BS 4987) (71) are used extensively on minor urban roads where traffic stresses are less. A reasonable service life is achieved and there is little difficulty in maintaining adequate skid resistance. Skidding accidents are rare on the minor roads (see Section 2.5.8) because, compared with the main roads, traffic is light and exerts little polishing action, frictional demand levels are low, vehicle speeds are low and there are fewer conflicts.

4.5.2 Hot-rolled asphalt.

Hot-rolled asphalt, to BS 594, is the standard wearing course surfacing on main roads in Great Britain. In the TRRL pavement design guide Road Note 29 (72) it is the only wearing course recommended for pavements with a design life in excess of 2.5 million standard axles (equivalent to about 300 commercial vehicles daily for 20 years). In London almost all the Principal roads are surfaced with hot-rolled asphalt. It has good load-spreading properties, is dense, impermeable and very durable. In London the average structural life of a hot-rolled asphalt wearing course is about twenty years.

Hot-rolled asphalt consists of a stiff binder/sand/filler mortar with added coarse aggregate. The sand and the coarse aggregate are each virtually single-sized and hence the resultant mix is gap-graded. Crushed rock chippings are rolled into the surface to provide a coarse-textured running surface.

The binder may be a refinery bitumen, a blend of pitch and bitumen (20-25% pitch) or a 50:50 blend of fluxed Trinidad lake asphalt and bitumen. Please and Lamb (73) have shown that fluxed lake asphalt and pitch-bitumen binders oxidise more rapidly than refinery bitumens on exposure to the atmosphere. The exposed surface of the mortar can become extremely smooth, especially when it has been softened by oil droppings or when the binder content is high. They found that the use of a rapidly-oxidising binder significantly improved the skid resistance on all but very heavily-chipped surfaces. The skid resistance improvement is brought about in two ways. Firstly, the degradation of the binder leads to the wearing away of the upper surface of the mortar, exposing unpolished grains of sands and coarse aggregate particles, thus improving the microtexture. Secondly, the removal of some of the mortar surrounding the chippings (or exposed coarse aggregate) improves the macrotexture.

A binder having a penetration of 50 (at 25°C) is generally used. Occasionally a 35 pen. binder is used at sites such as bus stops where traffic stresses are very severe and a 70 pen. binder may be used at very lightly-trafficked sites or in areas which are much colder and/or wetter than average.

The filler is usually powdered limestone, although Portland cement is used occasionally. The fine aggregate is usually a natural sand but crushed rock sands are sometimes used, especially in areas where there are no suitable natural sands, and can produce a very stable mix.

The coarse aggregate may be crushed rock, gravel or slag. The coarse aggregate content is usually 30% but on very heavily-trafficked roads it is sometimes increased to 35 or 40% in an attempt to improve the stability. This also helps to prevent excessive embedment of chippings under traffic but can lead to difficulty in embedding the chippings sufficiently to hold them securely in place. High stone content mixes (with 50-55% stone) are used occasionally. With these mixes it is not possible to roll chippings in and the skid resistance is determined by the properties of the coarse aggregate in the mix. The coarse aggregate must, therefore, have a sufficiently high PSV and be resistant to abrasion. One problem with high stone content wearing courses is that they are likely to be pervious, particularly in the early part of their life, and may therefore need to be sealed with a surface dressing.

In principle, the PSV of the coarse aggregate in a chipped hot-rolled asphalt should not influence the skid resistance because the chippings should be abutting and the vehicle tyres should not be in contact with the asphalt matrix. In practice, of course, full shoulder to shoulder contact between the chippings is impossible to achieve and there will be some contact with the asphalt. It is, therefore, necessary to ensure that the coarse aggregate is not unduly polish-susceptible. The DTp specification requires a minimum PSV of 45 for the coarse aggregate at 'difficult' and 'average' sites. Some authorities require that the PSV should be the same for the coarse aggregate as for the chippings.

Chippings are rolled into the surfacing immediately after it has been spread and lightly compacted by the paver and before final compaction. The chippings are 20 or 14 mm nominal size and are coated with binder to improve adhesion. For heavily-trafficked high-speed roads and hazard sites BS 594 requires that the rate of spread should be the maximum practical rate consistent with permanent retention of the chippings in the asphalt. It gives a guide to the target rate of spread based on the Size and Shape Index which is the percentage of undersized chippings plus the flakiness index. A typical target rate of spread for 20 mm chippings is 11.5 kg/m². There is a marked reluctance on the part of laying contractors to attempt to achieve the target rate of spread. If the chippings are spread at the target rate but are not uniformly distributed then there will be many 'over-riders' which will become detached when the road is opened to traffic. Nevertheless, it is necessary to achieve the target rate if the minimum texture depth of 1.5 mm is to be attained on high-speed roads. In urban areas the high texture depth is not required and BS 594 suggests that the target rate may be reduced (1.5 kg/m² lower for 20 mm chippings). This is unfortunate because it is still necessary to achieve a dense mosaic of chippings to obtain the maximum benefit from the chipping microtexture for good low-speed skid resistance.

The PSV of the chippings should be appropriate for the needs of the particular site (as discussed in Chapter 5). One consequence of the very long life obtained with hot-rolled asphalt is that there are many sections of road where, although the wearing course is old, it is still structurally sound but is excessively slippery because it was laid at a time when there was little awareness of the importance of aggregate polish-resistance and a low PSV chipping was used. Clearly, when the surfacing has become structurally unsound it would be replaced using a chipping with a higher PSV but earlier replacement would entail the forfeiture of the residual structural value and this might need to be offset against any possible saving in accident costs.

Hot-rolled asphalt wearing courses are normally laid to a thickness of 40 mm. In urban areas surfacing costs are relatively high because of the difficult operating conditions and the need to do much of the work at night or at weekends to avoid excessive traffic congestion. In London in 1983 the cost of supplying and laying a hot-rolled asphalt wearing course was approximately £4/m². **

Additional costs arise when a wearing course is replaced in an urban environment because of the need to either remove the existing wearing course or raise the ironware, kerb and footway levels to

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** Unless otherwise stated all costs quoted for materials are for mid-1983 on main roads in London.

accomodate the additional thickness of surfacing. Removing the existing wearing course costs about £1-25/m². Raising the level of the gulleys, manhole covers, etc. adds about 30% to the basic cost, i.e. an extra £1-20/m². It is necessary to raise kerb and footway levels in about 50% of contracts where the new wearing course is laid on top of the old one, at a cost equivalent to about £2/m².

4.5.3 <u>Delugrip.</u>

This is a proprietary surfacing material which was developed jointly by Dunlop Ltd and the University of Birmingham (<u>74</u>, <u>75</u>). It was the outcome of a collaborative research programme involving the development of a rational design method for bituminous mixes. The object was to produce a surfacing with good skid resistance, durability, resistance to deformation, high structural value and low noise generation. The method involves first establishing a design grading (which may be continuous or gap-graded), taking into account the packing properties of the proposed aggregates, to give the optimum voids content and the desired surface texture and then establishing the optimum binder content for the design grading. An important feature of the mix is the incorporation of two types of aggregate, both with a high PSV but having widely differing abrasion resistance, so that differential wear takes place under trafficking and the macrotexture is maintained.

Over 250 sections of Delugrip have now been laid, of which about 60 are on Principal roads in London. They closely resemble dense bitumen macadam in appearance and composition, although, in principle, the design method could produce a very wide range of mixes. A bitumen binder of penetration 50 or 70 is used, depending on traffic intensity. The first GLC trial sections were laid in 1973 on the A4 in Hammersmith, with 2,900 commercial vehicles passing over the sections each day. The material was laid to a thickness of only 19 mm, using Craig-yr-hesg (PSV 67, AAV 7) and Haughmond (PSV 62, AAV 4) aggregates. After 12 years it is still in a structurally sound condition (but see other comments below). The SFC in 1983 was 0.52 which is substantially higher than would normally be achieved in London with chippings of similar PSV in hot-rolled asphalt (see Sect.4.4). In 1975 the hot-rolled asphalt wearing course on Hammersmith Flyover was replaced with Delugrip. This increased the

SFC from 0.30 to 0.45, producing a 74% reduction in wet-road accidents.

Maximum texture depths on Delugrip are only moderate (about 1 mm) but Lees and Katekhda (76) have demonstrated that texture depth measurements can be misleading and that the drainage characteristics of Delugrip are superior to those of a chipped hot-rolled asphalt of the same texture depth. This is because the surface voids in the Delugrip are all interconnected and so are more effective in dispersing surface water than are the voids in hot-rolled asphalt, some of which may be discrete. The surface is very effective in reducing spray thrown up by vehicle tyres. Tyre noise is also perceptibly less than on most other surfacings. Replacing the hot-rolled asphalt wearing course on Hammersmith Flyover with Delugrip reduced the noise level by 3 dBA.

The material is normally laid at a thickness of 20-40 mm depending on threshold levels and pavement stiffness. The cost in London has been about 20% higher than an equivalent thickness of hot-rolled asphalt. In principle, it should be cheaper because the content of the relatively expensive binder is reduced (by about one-fifth) and the chipping operation is eliminated. However, the need to handle two types of aggregate in a range of sizes increases the production costs. The design method entails a considerable amount of laboratory testing before and during production. The material is less tolerant than hot-rolled asphalt and requires greater supervision and control at all stages of production, laying and compaction.

Delugrip has to some extent failed to live up to its early promise in London. Although many of the sites have given an SFC about 0.10 higher than would be expected with hot-rolled asphalt (with chippings of the same PSV as the aggregates used in the Delugrip) a substantial number have performed no better than a comparable hot-rolled asphalt. At several sites the material has been too rich in binder and the SFC has been very low. There are now doubts about durability. Originally it was predicted that, since it was a dense, impervious material with mechanical properties comparable with hot-rolled asphalt, it would have a similar life (about 20 years). However, at the first full-scale site in London (a 1.5 km length of the A206 at Bostall Hill, Greenwich) it failed structurally and had to be replaced after only eight years. Several other early sites are now showing signs of distress.

4.5.4 Pervious macadam friction course.

Friction courses are pervious bitumen macadams which were originally developed by the Air Ministry for use on airfield runways to reduce the likelihood of aquaplaning. They are laid on an impervious substrate; instead of draining to the edge of the road across the surface, the rainwater flows into the surfacing and across the top of the substrate. This reduces tyre splash and spray, and improves high-speed skid resistance because it provides a very effective means of removing bulk water from the tyre/road interface. Additional benefits are a reduction in light reflection in wet conditions, a perceptible reduction in tyre noise and lower rolling resistance. Significantly less noise is generated on friction courses than on other types of surfacing of equivalent high-speed skid resistance.

The use of friction courses on roads was pioneered by Warwickshire County Council in the late 1960's and has been reported by Vallis (77). The original Air Ministry specification was used with a 200 pen refinery bitumen binder but with high-PSV aggregate to give a good low-speed skid resistance. A thickness of 20 mm was used at first but this was increased to 30 mm to prevent fretting. It was reported that, although the initial rapid draining properties reduced after a few years, the surfaces remained permeable. An effective life of at least 10 years was obtained in Warwickshire, providing the material was laid properly. However, GLC trial sections (laid in 1972 on A2, Greenwich) were found to have closed up and become impervious after only 4 years under very heavy traffic (3,800 commercial vehicles each way daily). Nevertheless, although they were no longer functioning as drainage layers, they continued to provide a very good skid resistance, giving an SFC of 0.56 in 1976. The Haughmond stone used in the mixes had a PSV of 62. Thus, the SFC is very much higher than would have been achieved using Haughmond chippings in hot-rolled asphalt (about 0.37 - see Sect. 4.4). Similarly, a trial section, using a stiffer binder (70 pen) and Craig-yr-hesg stone (PSV 67), laid in 1979 on A4 Hammersmith, carrying 4,000 vehicles per day had become impervious by 1983 but was giving an SFC of 0.52.

These results indicate that in urban conditions the skid resistance performance of a friction course is undoubtedly superior to that of a chipped hot-rolled asphalt with aggregates of similar PSV. This finding is in conflict with the TRRL view (78) that friction courses are no better in this respect than other commonly used surfacings. There is clearly considerable scope for the use of friction courses as anti-skid surfacings on urban roads either as a thin overlay or (where the pavement is of adequate strength and is impervious) as a replacement wearing course. Friction courses are usually considered to have no structural value but Potter and Halliday (79) have shown that 40 mm of friction course is equivalent to 16 mm of hot-rolled asphalt in terms of load-spreading power.

The cost of supplying and laying a 30 mm thick friction course in London is about £2-50/m².

4.6 CONCRETE

Concrete pavements are relatively rare on urban main roads in Great Britain. They are found mostly on roads in housing estates or industrial estates. Levels of frictional demand on such roads are generally very low and skidding accidents are rare. Many sections of concrete road were constructed in the pre-war years and have now been covered with a bituminous surfacing (mainly because of structural maintenance problems on old concrete slabs). These early concrete roads had a reputation for poor skid resistance under heavy traffic. However, in recent years increased knowledge of the mechanisms involved in the loss of skid resistance has led to improvements in materials and laying techniques. A significant proportion of the motorways constructed in the past ten years have concrete running surfaces which are providing a level of skid resistance generally comparable with that obtainable with hot-rolled asphalt.

Laboratory experiments and road trials carried out by the TRRL and the Cement and Concrete Association (80,81,82) showed that the mechanism of polishing and wear of concrete leading to loss of skid resistance is different in some respects from that for bituminous surfacings. The PSV of the coarse aggregate in the mix was found to have a relatively small effect on the skid resistance because the coarse aggregate particles cover only about 12% of the exposed surface area. The fine aggregate in the mix has the greatest influence on the skid resistance. Hard, natural sands of high silica content gave a higher SRV than did relatively soft natural sands. Under traffic there is differential wear between the hard sand particles and the surrounding cement paste, and the sand particles stand proud of the surface thus giving a good microtexture. Crushed rock fines from a high-PSV gritstone with good abrasion resistance also gave a high SRV because the differential wear within each aggregate particle produced a good microtexture. Certain sands containing a high proportion of limestone performed very badly. Consequently, the DTp Specification for Road and Bridge Works (68) was amended to exclude from the top 50 mm of a concrete pavement any fine aggregate containing more than 25% of calcium carbonate.

The fine aggregate content and the compressive strength of the concrete were also found to have a significant but small effect on SRV. Increasing the fines content gave a slightly higher SRV, presumably because it increased the proportion of fine aggregate particles exposed at the surface. A decrease in the compressive strength gave a slightly higher SRV, presumably because the weaker cement paste wore away more rapidly giving greater exposure of the fine aggregate particles at the surface.

TRRL (83) have now developed an accelerated polishing test, based on the aggregate PSV test, using samples of mortar made from the proposed sand. The test gives the Polished Mortar Value, PMV. Road experiments are now in progress from which it is hoped to establish the relationship between the properties of the constituent materials (including the PMV), traffic intensity and equilibrium SFC.

A coarse macrotexture is obtained by brushing the surface of the freshly-compacted concrete transversely with a wire broom. The texture thus achieved is predominantly in the surface mortar and may be worn away under heavy traffic. A more positive, long-lasting texture is produced by the use of a machine developed by the Cement and Concrete Association to form transverse grooves in the plastic concrete. This gives a macrotexture which is very effective in reducing the fall-off in SFC with increasing vehicle speed and also reduces tyre spray. Unfortunately, it also leads to a high level of tyre noise. Randomising the spacing of the grooves helps to reduce the perceived noise level (84) but many people still find it objectionable and the use of the grooving technique is now restricted to high-speed roads in non-residential areas.

4.7 SURFACE DRESSING AND OTHER SURFACE TREATMENTS

4.7.1 Surface dressing.

Conventional surface dressing is a relatively cheap surface treatment which is used very extensively on rural roads and on minor roads in urban areas to seal pervious or crazed areas and to restore skid resistance. It consists of a single layer of chippings spread on a thin film of thermoplastic binder. The binder may be cutback bitumen, road tar, bitumen emulsion or a tar-bitumen blend. It is sprayed on to the road surface and covered with chippings which are then rolled to bed them into the binder film. The binder must be sufficiently fluid to wet the chippings but must be stiff enough to support them and hold them firmly in place in the critical early life of the dressing. The cohesive strength of conventional binders is low and the chippings are readily detached from the binder, particularly at locations where vehicles are braking, turning or travelling at high speed. Excessive loss of chippings leaves a film of binder on the running surface which can be very slippery when wet. If the surface dressing is laid on a bituminous substrate the chippings gradually become partially embedded in the substrate and this improves the stability of the dressing. Under heavy traffic, particularly when it is slow-moving as in urban areas, the embedment can become excessive, macrotexture is lost and some of the binder is forced to the surface. This is known as 'fatting up'. In extreme cases the chippings can become completely submerged in the binder film resulting in a very low SFC of the order of 0.15 .

Guidance on the selection of the appropriate grade and rate of spread of binder and the size of the chippings is given in Road Note 39 (85). The chipping size should be as small as possible (minimum practicable size 6 mm) so that the quantity of materials is minimised but should be sufficiently large to resist excessive embedment. Consideration must, therefore, be given to the traffic intensity and the hardness of the existing surface. Chippings need to be larger at sites where traffic is heavy or the substrate is soft. Road Note 39 categorises sites in terms of the daily commercial vehicle flow and the surface hardness as measured with a penetrometer. Recommendations are given for chipping size and rate of spread of binder for each category. A particular problem on urban roads is that the surface hardness is often highly variable because of extensive patching resulting from the reinstatement of openings by statutory undertakers. This can make it impossible to assign a representative hardness value for a given section of road.

As with hot-rolled asphalt the chippings for surface dressing should have good resistance to polishing and abrasive wear, and should be angular but not flaky. To improve adhesion the chippings are sometimes laid hot or are lightly coated with binder before laying.

Surface dressing is a very cheap process, typically costing only about 40p/m^2 on rural roads and 80p/m^2 on urban roads. The average life is 5-7 years but, of course, this applies only to those low-stress areas where the treatment is feasible. It is unfortunate that it is rarely possible to use conventional surface dressings successfully on heavily-trafficked urban roads. Premature failure is very common in these areas because the limiting conditions inherent in the process overlap, i.e. a considerable thickness of binder is required to prevent dislodgement of chippings during the early life of the dressing but this leads to fatting up and loss of texture when the inevitable embedment of the chippings occurs under traffic. The need for improved binders has long been recognised and some progress has been made in recent years in developing new materials (86,87).

4.7.2 Surface dressing with improved binders.

Polymer-modified bitumen binders are now available (e.g. Surmac marketed by BP plc). These give improved early-life chipping retention and enable surface dressing to be laid at some heavily-trafficked locations but are not sufficiently strong for use at braking areas on urban main roads and do not give improved resistance to chipping embedment.

The binders are substantially more expensive than conventional binders. In London a surface dressing with a polymer-modified binder costs about £1-80/m² compared with 80p/m² for a conventional surface dressing.

A bitumen-extended epoxy resin binder for use with conventional aggregates has been developed by the Shell International Petroleum Company (88) and is marketed as Erophalt. A trial section was laid in London in July 1981 and is performing satisfactorily. The test section was Lambeth Palace Road which is fairly heavily trafficked (18,000 vehicles each way per day of which 2,700 are commercial vehicles) and has several bends. The wearing course was a very old (20-25 years) hot rolled asphalt. It was structurally sound but the SFC was only about 0.30 and there was a high incidence of wet-road skidding accidents. The Erophalt binder was laid at a rate of 1.2 to 1.3 l/m² and covered with 10 mm Gore chippings (PSV 67, AAV 7). Light traffic was allowed to travel very slowly over the surface for 1 to 2 hours to bed the chippings in, after which time normal traffic flow was permitted. There was some initial loss of chippings, possibly due to the need to allow full traffic flow at normal speeds before the binder had cured fully, but there has been little deterioration subsequently. The binder is holding the chippings firmly in place and is sufficiently stiff to resist embedment of chippings into the asphalt substrate. After three years the SFC was 0.56. More importantly, perhaps, is the fact that the accident rate has been reduced very substantially. Wet-road accidents were reduced from 25 to 6. There were 7 wet-road skidding accidents in the two years immediately before treatment and none in the following two years.

The cost of the treatment was £3-25/m². The life is not yet known but is likely to be in excess of 6 years.

4.7.3 Resin/bauxite treatments.

The most effective surface treatment for use at high-stress urban locations is a form of surface dressing using a thermosetting bitumen-extended epoxy resin binder with small-sized calcined bauxite chippings. It is extremely durable and gives an exceptionally high skid resistance (SFC 0.60 - 0.75). The calcined bauxite aggregate has a very high resistance to polishing (PSV 75) and to abrasive wear (AAV 2). The binder has a bond strength sufficiently high to resist traffic stresses tending to dislodge the chippings and is hard enough to prevent chipping embedment even though the chippings are of very small size (1-3 mm).

In the late 1950's James of TRRL (89) discovered the remarkable properties of calcined bauxite as a road aggregate and laid some small trial patches on the road using an epoxy resin binder. In 1966 Hatherly of the GLC (90) carried out road trials to establish the feasibility of using the very small bauxite chippings as a surface dressing aggregate on heavily-trafficked roads in London. He examined a number of binders, including polyesters and epoxy resins, and found that a bitumen-extended epoxy resin developed by Shell Research Ltd performed most satisfactorily. Full-scale road trials followed in 1967 when several accident black spot sites were treated successfully, using spray application techniques with equipment developed by Universal Highways Ltd (now Redland Prismo plc) under contract to Shell. The dressing proved to be extremely durable and gave a much higher skid resistance than could be achieved with conventional materials. Furthermore, although the process was expensive, the reduction in accidents at the treated sites was such that the cost of treatment was effectively recovered by savings in accident costs within about three months (91). Encouraged by these results, Hatherly embarked on a major anti-skid surfacing program, eventually treating some 2,000 accident sites in London (92). The resin/bauxite process has become established as the most effective anti-skid treatment at high-risk, high-stress locations. The process was marketed by Shell under the proprietary name Shellgrip. Redland Prismo subsequently produced an equivalent system which is known as Spraygrip; references to Shellgrip in this study should be taken as including Spraygrip also.

The binder is a two-component system. Component A contains the resin and a proportion of oil which reduces the viscosity and acts as an extender. Component B contains the curing agent together with bitumen and oil extenders and accelerators. The two components are heated, metered, mixed and sprayed on to the road surface at a minimum rate of 1.35 kg/m^2 (1.25 l/m^2). The binder is then covered with an excess of calcined bauxite chippings (1-3 mm size) and the treatment is allowed to cure. The cure time is between 1 and 7 hours depending on the ambient temperature. The excess chippings are then removed and the road opened to traffic.

The small chipping size was used originally because larger sizes were not available in sufficient quantity. Initially there were doubts about the durability of such a small-sized chipping and about the feasibility of achieving and maintaining a reasonable texture depth. All of these doubts proved to be unfounded. The bauxite is extremely hard and abrasive wear of individual particles under traffic is minimal. Traffic stresses on small individual particles tending to dislodge them can be very high but the bond strength of the binder is sufficient to resist them. Similarly, the binder is strong enough to resist embedment of the chippings. The initial texture depth is high - about 1.5 mm but under traffic this falls rapidly and levels out at about 0.9 mm . This is more than than adequate for bulk water drainage from the tyre/road interface at urban speeds and, bearing in mind the high SFC, is sufficient to ensure good skid resistance on high-speed roads.

Calcined bauxite from Guyana (RASC grade) was used in the original trials and this has proved to give the best performance in terms of both durability and level of skid resistance attained. Calcined bauxites from other sources (Australia, China, Ghana, India, Ireland) have been tested but road trials in London (65) have shown that although some of them are satisfactory they are not as effective as that from Guyana. Trials with small-sized natural roadstones showed that none of the high-PSV stones were sufficiently resistant to abrasive wear and the harder stones did not have adequate polish resistance. One disadvantage of Shellgrip is increased tyre wear. Studies by Dunlop (unpublished) have shown that the rate of tyre wear on resin/bauxite surfaces is substantially greater than on conventional surfaces, particularly where traffic is braking or turning. This has not been a significant disbenefit up to the present because Shellgrip has been laid at localised sites representing only a very small proportion of the total road length. The treatment is not recommended for use on concrete because, for reasons which have not yet been established, there has been a high incidence of premature failure on such surfaces.

The price of the treatment in London is approximately £7-25/m². The average life is about 12 years providing the substrate on which it is laid is sound. In practice, it is sometimes necessary to replace the wearing course before the anti-skid surfacing has reached the end of its life and the average service life in London is about 10 years.

4.7.4 Slurry seals.

A conventional slurry seal is a mixture of fine aggregate, filler, bitumen emulsion and water. The materials are mixed and laid at ambient temperature, with a spreader box being used to screed the mixture on to the road surface at a thickness of 1.5 to 3.0 mm. Slurry seals have been used extensively to seal lightly trafficked roads and motorway hard shoulders but are not considered to be sufficiently durable for use on heavily trafficked roads. However, a proprietary material (Ralumac) which has recently been developed in Germany is undergoing trials on main roads in London (and elsewhere) and the early results are very encouraging. A polymerised bitumen binder is used which is much stronger than a conventional binder and permits the material to be laid to a greater thickness using larger-sized aggregates. This gives greater durability and, being laid as a screed, the additional benefit of correcting minor surface irregularities in the existing wearing course thus improving the riding quality. This can be an important advantage in urban areas since it is not uncommon for a wearing course to have to be replaced because a series of statutory openings has rendered the riding quality unacceptable.

Ralumac was laid at seven sites on Principal roads in London in the spring of 1983 at a thickness of 10 mm using Dry Rigg aggregate (PSV 63) of maximum size 6 mm, together with a fine moraine sand. The most heavily trafficked of the trial sites was the A205 Upper Richmond Road which carries 15,000 vehicles each way per day of which 1,600 are commercial vehicles. After 12 months the mean SFC at this site was 0.50.

The cost of the treatment in London was £1-85/m^2. The life is not yet known but a minimum of 5 years is anticipated.

4.7.5 Surface retexturing.

Various methods are available for renovating fatted surface dressings or hot-rolled asphalts in which the chippings have become excessively embedded (93,94). The surplus binder or asphalt mortar surrounding the chippings may be removed by heating the surface to carbonise the binder in the upper 1-2 mm; the degraded material is then removed by brushing, by air blasting or simply by the action of traffic. It is also possible to achieve the same result by using chemical solvents to soften or dissolve the binder and so aid the removal of the surplus material surrounding the roadstone. Both of these methods are used principally to improve macrotexture but an improvement in microtexture (and hence low-speed skid resistance) may result from the increase in the area of exposed roadstone.

The surplus binder or asphalt mortar may also be removed by blasting the surface with abrasive particles. As well as increasing the texture depth this also produces a more positive improvement in microtexture by removing the polished surface of the exposed aggregate particles, thus restoring them to their untrafficked condition (although the treatment will tend to round their edges). The improvement in microtexture of individual aggregate particles may be short-lived because they will again become polished under the action of traffic. The treatment could, of course be repeated but this would increase the likelihood of roadstone being lost because of excessive removal of the surrounding binder or asphalt mortar. On urban roads the process is probably most suitable as a means of temporarily restoring skid resistance pending the implementation of a more permanent remedy (i.e. resurfacing or anti-skid surface treatment). The current cost of this treatment is about £1/m².

4.8 SUMMARY.

(i) The microtexture of the aggregate particles exposed at the road surface has a dominant influence on wet-road skid resistance at urban vehicle speeds.

(ii) Surface macrotexture is relatively unimportant at urban speeds.

(iii) The equilibrium SFC of a conventional bituminous wearing course or surface dressing can be predicted from a knowledge of the aggregate polished stone value and the traffic intensity.

(iv) SFC values on roads in London surfaced with hot-rolled asphalt are on average 0.11 lower than would be predicted by the relationship between SFC, PSV and traffic flow defined in LR504.

(v) Many of the cheaper surfacings that are used on rural roads are unsuitable for urban main roads because of inadequate durability under more arduous conditions.

(vi) Hot-rolled asphalt is the most suitable wearing course surfacing for general use on urban main roads but cannot maintain a high SFC at heavily-trafficked high-stress locations.

(vii) Epoxy resin/calcined bauxite surface dressing gives the highest attainable skid resistance.

(viii) A wide range of wearing course materials and surface treatments is now available which can provide intermediate levels of skid resistance.

CHAPTER 5

PROPOSED SKID RESISTANCE STANDARDS AND THEIR RELEVANCE TO URBAN ROADS

5.1 INTRODUCTION

In Chapter 3 it was shown that frictional demand levels in normal driving are relatively low. To some extent the demand is regulated by the desire of drivers to avoid the physical discomfort caused by harsh braking, accelerating or manoeuvring. In urban areas drivers are constrained by low speed limits and by the close proximity of other road users. The QMC study of decelerations in London (34) demonstrated that a friction coefficient of 0.40 is more than adequate for routine braking on urban main roads. Although, as was shown in Chapter 4, it is technically possible to maintain a high level of skid resistance on all roads it will be shown in Chapter 9 that it would not be cost-effective and might be undesirable for other reasons. It would be relatively easy to maintain a moderate minimum SFC of say 0.40 throughout the network. This would accommodate the needs of almost all road users who are driving carefully and anticipating the actions of others. A skid would occur only as a consequence of unusually harsh braking, accelerating or manoeuvring and would be attributable to road-user error. This would be an irresponsible policy because it is clearly necessary to make some provision for the emergency situations which will inevitably arise, with the driver braking sharply or swerving to avoid a collision and generating a high frictional demand. Consideration must be given to providing higher levels of skid resistance at locations where frictional demand is likely to be higher than average and particularly where emergency braking is likely to occur frequently. This was the approach suggested by Giles (12) who formulated the most widely known set of standards for minimum skid resistance. These standards were adopted, with slight modifications, by the Marshall Committee on Highway Maintenance and were used as the basis for the standards proposed by Salt and Szatkowski.

5.2 GILES PROPOSALS

5.2.1 Introduction

The standards proposed by Giles in his paper to the Institution of Civil Engineers in 1956 are shown in Table 5.1. Four categories of site are defined, for three of which minimum SFC values are suggested. The fourth category ('proved sites') is for locations which have a low

TABLE 5.1

Site categories and SFC values proposed by Giles (12)

CATEGORY	TYPE OF SITE	SFC REQUIREMENT
A	'MOST DIFFICULT SITES', such as (1) roundabouts (2) bends with radius less than 500 ft on fast derestricted roads (3) gradients, 1:20 or steeper, of length greater than 100 yd (4) approaches to traffic lights on derestricted roads	Above 0.6
B	'GENERAL REQUIREMENTS', i.e. roads not covered by categories A and C	Above 0.5
C	'EASY SITES', e.g. mainly straight roads with easy gradients and curves and without junctions, and free from any features such as mixed traffic, especially liable to create conditions of emergency.	Above 0.4
D	'PROVED SITES', e.g. roads with coefficients below 0.4 which, because of factors such as very slow or infrequent traffic, cannot be shown by accident studies to be above normal danger.	-

SFC (0.40 or less) but are known to have an acceptable wet-road skidding accident record.

Giles formulated his proposals after carrying out a very comprehensive study of vehicle performance, vehicle frictional demand in braking and manoeuvring, and the characteristics of skidding accident black spots. He first considered whether there was an upper limit to frictional demand in braking or cornering, imposed by performance limitations (braking efficiency, body roll and tendency to overturn). He concluded that cars could utilise to the full the maximum friction likely to be available between tyre and road surface, even in dry conditions. He suggested that the minimum skid resistance requirements are mainly governed by the way in which vehicles are normally driven. As discussed above and in Chapter 3, drivers normally operate their vehicles in such a manner that the level of frictional demand is low but occasionally an emergency arises and the frictional demand is then very high.

Giles examined a number of skidding accident black spots in south-east England. He found that nearly all of them were on heavily-trafficked roads and in almost every case were associated with some 'difficult' layout feature (e.g. low-radius bend, steep gradient, road junction) where vehicles may need to execute manoeuvres requiring a higher skid resistance than normal. He compared sites of similar layout and found that the mean SFC at skidding sites was about 0.36 compared with about 0.50 at sites selected at random. He looked at the distribution of SFC values at sites where there were repeated skidding accidents and at randomly-selected points and calculated the relative liability that a site would become the scene of repeated skidding accidents. He concluded that, whilst a site with SFC above 0.60 might by chance sometimes be the scene of a skidding accident, the risk that it would be the scene of repeated skidding accidents was extremely small. The risk became measurable at SFC 0.55-0.60 and then increased rapidly, by more than 20 times at SFC 0.40-0.45 and at SFC 0.30-0.35 was 300 times greater. The risk was so great at the lower values of SFC that it became the dominant factor, largely outweighing the effects of differences in layout or the amount of traffic.

Having defined target SFC values that he considered to be appropriate for each site category Giles conducted a survey on a sample of existing surfacings to establish whether the target values were attainable. He found that only 10% of A roads in south-east England and 6% of all classified roads in a typical county were below 0.40. He concluded that the proposed target values were realistic. However, he also surveyed a number of sites on heavily-trafficked city roads and found that 38% were below 0.40 and 81% below 0.50. He commented that in such areas 'special difficulties may arise in meeting the values suggested'. Thus, at the outset Giles acknowledged that the proposed minimum values were not necessarily realistic for urban roads. He did stress, however, that the proposed values were intended as a very tentative guide, and the basis for further study, from which, ultimately, the best values to adopt in any circumstances might be properly established. That was in 1956. No such studies relating to urban roads have been reported to date.

5.2.2 Characteristics of skidding sites.

The majority of the skidding accident sites in Giles's study were on rural roads and his findings are not necessarily valid for urban conditions. In rural areas skids tend to occur at well-defined locations such as Giles described, i.e. low-radius bends, roundabouts and steep gradients. They are frequently the result of driver misjudgement in attempting to negotiate a bend at too high a speed. It is interesting to note that in about half of the skidding accidents in Giles's study no braking was involved. In contrast, a typical urban skidding accident occurs when a driver is forced to apply maximum braking effort in an emergency situation which has arisen because of the unexpected behaviour of another road user, e.g. the vehicle ahead stopping suddenly or a pedestrian stepping into the road without warning. Vehicle and pedestrian behaviour patterns and interactions are much more complex in urban areas and this makes it very difficult to define the skidding risk at individual locations.

In order to investigate the characteristics of skidding accident black spots in London a transparent, computer-plotted map overlay was prepared to a scale of 1:50,000 showing the location of all the wet-road skidding accidents in the GLC area in 1970. That particular year was selected because it was the earliest year for which computer-stored accident records were available and was at a time when relatively few accident sites in London had been treated with

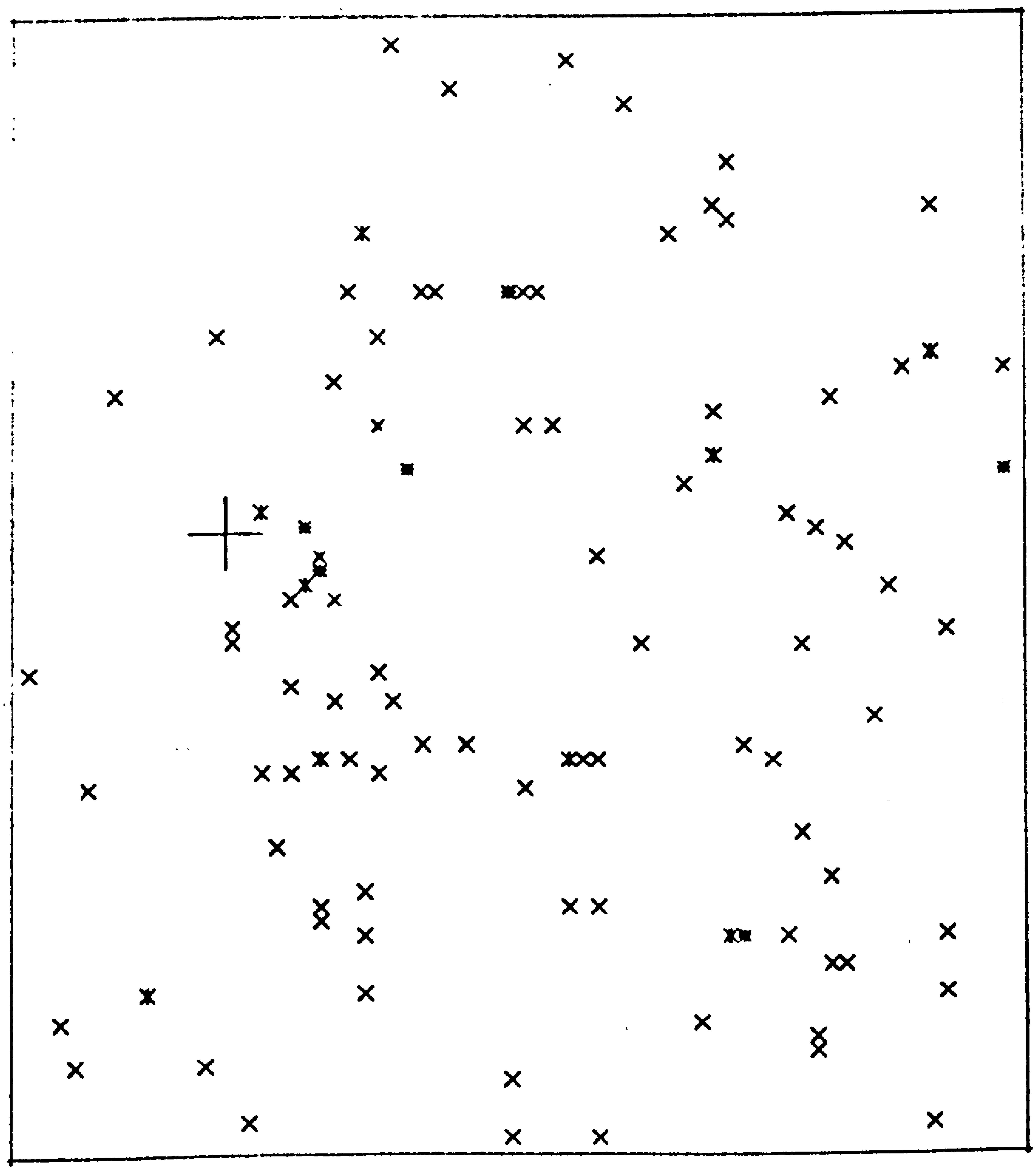

FIG. 5.1 Section of computer-plotted map overlay showing location of wet-road skidding accidents.

anti-skid surfacing. A portion of the overlay is shown in Fig. 5.1. Forty sites were identified where there was a cluster of skidding accidents (3 or more in the one year). The overlay was superimposed on an Ordnance Survey (OS) map of the same scale and the approximate national grid co-ordinates were defined for each site. The GLC GASGET program was used to produce a listing for each site of details of all accidents within 100 m of the defined point. From the plain language descriptions the precise geographical location of each skidding accident cluster was established and large-scale (1:1250) OS maps were obtained so that the road layouts could be examined. The maps were used to determine whether there was

- a ROAD JUNCTION
- a SHARP BEND (radius less than 150 m)
- a STEEP GRADIENT (1:20 or steeper)

From the accident records it was possible to define the presence of

- TRAFFIC LIGHTS
- PEDESTRIAN CROSSINGS

and to determine the

- SPEED LIMIT
- ROAD CLASS

From accident records for each site a note was made of the number of

- ACCIDENTS IN ALL CONDITIONS
- WET-ROAD ACCIDENTS
- WET-ROAD SKIDDING ACCIDENTS

At several of the sites it became apparent that the 100 m radius encompassed other adjacent accident locations. Accordingly, at all of the sites each accident record was examined carefully and was discarded if the location description made it clear that the accident was more closely associated with an adjacent site.

The information on each site is shown in detail in Table 5.2 and is summarised in Table 5.3. For comparison, Table 5.4 shows the features noted by Giles in his study of wet-road skidding black spots in predominantly rural areas.

All of the sites where there were clusters of wet-road skidding accidents were on classified roads. These roads constitute less than a quarter of the road length in London but, as was shown in Section 2.5.10, they account for 84% of the skidding accidents.

site ref.	approx. grid ref.	road category	speed limit mile/h	accidents: wet skid	wet	total	% wet	site features: junction	round -about	ATS	pedest. crossing	sharp bend	steep incline
1	1913-8348	T	40	3	16	23	69.6	*		*			
2	2934-8848	T	40	4	10	23	43.5	*		*			
3	2365-8994	T	40	4	10	16	62.5	*		*			
4	2126-8555	T	40	3	4	4	100.0	*					
5	5122-9047	T	40	3	10	16	62.5	*	*				
6	5066-8974	T	40	3	5	13	38.5	*	*				
7	2464-8621	T	40	3	5	15	33.3	*		*			
8	3484-9970	T	40	4	6	12	50.0	*	*				
9	3175-8895	P	30	3	5	12	41.7	*		*			
10	3206-8747	P	30	4	8	24	33.3	*		*			
11	2907-8036	P	30	3	8	18	44.4	*		*			
12	2983-7837	P	30	3	3	7	42.9	*		*			
13	3002-8056	P	30	3	10	33	30.3	*		*			
14	2984-8125	P	30	4	9	17	52.9	*		*			
15	3261-6424	P	30	3	7	11	63.6	*		*			
16	3027-7896	P	30	3	6	15	40.0	*	*		*		
17	2725-7918	P	30	4	8	17	47.1	*			*		
18	2117-8385	P	30	3	9	20	45.0	*			*		
19	3756-8296	P	30	3	4	14	28.6	*			*		
20	3178-6203	P	30	3	3	7	42.9	*			*		
21	3639-7836	P	30	3	4	9	44.4	*			*		
22	2255-8306	P	30	4	5	10	50.0	*				*	
23	2347-7836	P	30	3	7	19	36.8	*					
24	3123-8644	P	30	3	4	7	57.1	*					
25	3751-9453	P	40	3	3	4	75.0	*					
26	3873-9435	P	30	4	6	6	100.0	*					
27	5066-8974	P	30	5	12	18	66.7	*					
28	3361-8721	P	30	3	3	4	75.0	*					
29	1834-7333	P	30	4	5	7	71.4	*				*	*
30	3604-8692	P	30	3	10	12	83.3	*					
31	3510-8934	P	30	4	4	6	66.7					*	
32	2495-7855	P	30	3	3	5	60.0						
33	4127-7385	P	40	3	5	8	62.5						
34	3865-8915	B	30	6	6	6	100.0	*				*	
35	1905-9142	B	30	4	4	7	57.1	*				*	
36	5055-9005	B	30	3	4	4	100.0	*				*	
37	5535-9044	B	30	3	3	4	75.0					*	*
38	4384-7793	B	30	3	8	14	57.1	*					*

T = Trunk P = Principal B = Borough

TABLE 5.2 <u>Wet-road skidding accident black spots in London (1970)</u>

TABLE 5.3

Features of skidding accident black spots in London

Feature	number of sites with feature	%
40 mile/h speed limit	10	26.3
road junction	34	89.5
roundabout	4	10.5
traffic signals	11	28.9
pedestrian crossing	6	15.8
sharp bend	7	18.4
steep incline	3	7.9
at least one of the above features	37	97.4

TABLE 5.4

Features of roads at skidding accident sites

compared with other roads in S.E. England (Giles, 1956)

Feature	% of skidding accident sites with feature out of a total of 128	% of random sample sites with feature out of a total of 100
STRAIGHT with no other feature	2	19
CURVE, radius less than 1500ft (460m)	7	33
BEND, radius less than 500ft (150m)	40	7
SLIGHT GRADIENT, slope less than 1:20	9	19
GRADIENT, slope 1:20 or more	39	26
JUNCTION at or within 50yd (45m)	45	51
ROUNDABOUT	10	-

Two of the sites were on derestricted roads. Since, for this study, urban roads are defined as roads in 'built-up' areas (i.e. with speed limits of 30 mile/h or 40 mile/h) these two sites were excluded from further consideration and are not shown in Table 5.2.
Of the 38 sites remaining, 10 had speed limits of 40 mile/h.

Eight of the sites were on Trunk roads, 25 on Principal roads and 5 on Borough roads. It is interesting to note that the Trunk road sites comprise 21% of the skidding black spots whereas Trunk roads constitute only 2% of the road length in London. This is, perhaps, a reflection of the fact that they are very heavily trafficked and higher numbers of accidents (and lower skid resistance levels) are to be expected. Furthermore, most of these roads have speed limits at the higher urban level (40 mile/h) and hence vehicle speeds tend to be higher. All eight of the Trunk road skidding sites had a speed limit of 40 mile/h and all but one were at light-controlled junctions or roundabouts.

A very high proportion (90%) of the skidding sites were at junctions. This is double the proportion found by Giles in his study. Forty-five percent of the London sites were light-controlled junctions or uncontrolled pedestrian crossings. Giles makes no mention of either of these categories; presumably because there were few, if any, in his sample.

A substantial proportion of Giles's skidding sites had major geometric deficiencies; at 40% there was a sharp bend (radius less than 150 m) and at 39% a steep incline (1:20 or more). These deficiencies were present at only 3 of the 33 Trunk and Principal road sites in London, although all 5 of the Borough road sites had them.

It is clear that the picture of a typical wet-road skidding accident site that emerged from Giles's study does not apply to Trunk and Principal roads in London. The sites are not predominantly in areas where there are geometric deficiencies but are at locations such as light-controlled junctions and pedestrian crossings, where there is a complexity of interactions and a correspondingly high incidence of emergency braking.

The overall wet-road skidding rate at the black spot sites was 53.7%, compared with an average of 15.5% in London generally in 1970. The rate at all 38 sites was above average.

A striking feature of the sites is the very high proportion of accidents occurring on a wet road surface. The average wet-road rate for London as a whole in 1970 was 27.4%. All of the sites were above this value and the overall average was 51.8%. This provides support for the view, held by many observers, that the proportion of accidents in the wet is a good indicator of the inadequacy of the skid resistance at a particular site. It is possible that there are many sites where the skid resistance is inadequate but the fact remains undetected because of under-reporting of skidding. "Percentage wet" could be a useful parameter for identifying such sites and will be investigated further in later Chapters.

5.2.3 SFC levels and relative risk of a site becoming a skidding accident black spot.

Figure 5.2 is a double histogram produced by Giles, comparing SFC values at the 128 wet-road skidding sites and at randomly-selected sites. There is a very marked difference between the two distributions. The mean SFC value at the accident sites is 0.36 compared with 0.50 at the random sites. None of the random sites has a value below 0.30 and none of the accident sites has a value in excess of 0.60.

No relevant SFC measurements are available for the London skidding accident sites described in the previous section because the GLC SCRIM test vehicle did not come into service until 1972, by which time a number of the sites had been resurfaced and in any case not all of the sites were on GLC roads.

Table 5.5 shows SFC values (measured in 1976) on the approaches to a group of 408 uncontrolled pedestrian crossings in London. The road surface at all of the sites was either hot-rolled asphalt or conventional surface dressing. Sites where anti-skid surfacing had been laid are not included. The table also indicates the number of sites at which wet-road skidding accidents were reported in the period

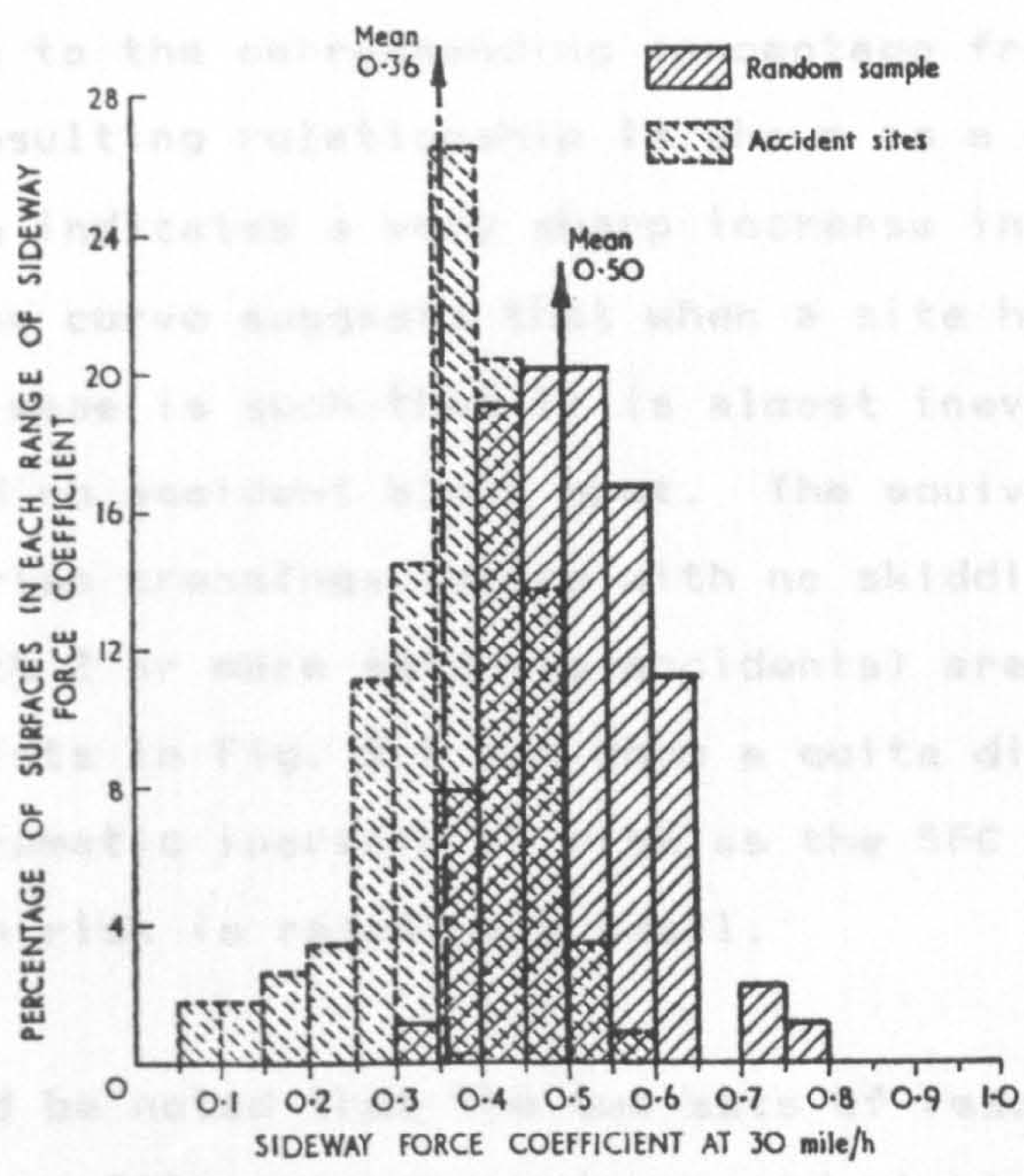

FIG. 5.2 <u>Comparison of SFC levels at wet-road skidding accident sites and random sites on class A roads in south-east England (Giles, 1956)</u>

1971-75 *. Figure 5.3 comprises three histograms showing the percentage distribution of SFC values of sites where there were no skidding accidents, one skidding accident and repeated (i.e. 2 or more) skidding accidents. It will be seen that there is very little difference between the three distributions. The overall mean SFC values at the skidding sites were only slightly lower than the value for the other sites - 0.33 and 0.33 compared with 0.34. In both groups of skidding sites 23% of the SFC values were below 0.30 but so were 18% of the values in the non-skidding sites.

Giles used the results shown in the histograms in Fig. 5.2 to establish the relationship between SFC and the relative liability that a surface will become the scene of repeated skidding accidents. He calculated the ratio of the percentage of skidding accident sites in each SFC range to the corresponding percentage from the random sample sites. The resulting relationship is shown as a curve on the graph in Fig. 5.4 which indicates a very sharp increase in risk as the SFC decreases. The curve suggests that when a site has an SFC of 0.32 or lower the increase is such that it is almost inevitable that it will become a skidding accident black spot. The equivalent results for the London pedestrian crossings (sites with no skidding accidents compared with sites with 2 or more skidding accidents) are plotted as individual points in Fig. 5.4 and show a quite different relationship. There is no dramatic increase in risk as the SFC decreases; the rate of increase in risk is relatively small.

It should be noted that the two sets of results are not strictly comparable since Giles was comparing accident black spot sites with randomly-selected sites, most of which would have been quite different in character from the accident sites, whereas the London sites were all pedestrian crossings (and their approaches) and hence were similar in character. It could be argued that, in order to investigate the relative effect of differences in skid resistance, Giles should have compared each accident site with a non-accident site of similar character. Another difference between the two sets of results is that the London SFC measurements were all made in a three-week period in the summer whereas for the accident sites Giles used SFC values

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* SFC values and raw accident data for this group of pedestrian crossing sites were obtained during an earlier investigation (95).

TABLE 5.5

SFC (1976) and wet-road skidding accident frequency (1971-75) at pedestrian crossings in London

SFC	NUMBER OF SITES					
	0 ACCIDENTS	1 ACCIDENT	2 ACCIDENTS	3 ACCIDENTS	4 ACCIDENTS	TOTAL
below 0.22	-	-	-	-	-	-
0.22	2	1	-	-	-	3
0.23	2	1	1	-	-	4
0.24	3	-	-	-	-	3
0.25	6	1	-	-	-	7
0.26	2	3	1	-	-	6
0.27	13	8	1	-	-	22
0.28	10	4	2	-	-	16
0.29	13	3	3	-	-	19
0.30	32	6	6	-	-	44
0.31	20	4	1	-	-	25
0.32	14	10	2	-	-	26
0.33	14	12	2	-	-	28
0.34	41	14	5	-	1	61
0.35	18	3	3	-	1	25
0.36	19	4	1	1	-	25
0.37	19	10	-	-	-	29
0.38	9	1	2	-	-	12
0.39	12	1	-	-	-	13
0.40	4	-	-	-	-	4
0.41	7	3	1	-	-	11
0.42	5	1	-	-	-	6
0.43	2	1	-	-	-	3
0.44	4	-	-	-	-	4
0.45	3	1	-	-	-	4
0.46	-	-	-	-	-	-
0.47	1	-	-	-	-	1
0.48	3	-	1	-	-	4
0.49	2	-	-	-	-	2
0.50	-	-	-	-	-	-
0.51	1	-	-	-	-	1
above 0.51	-	-	-	-	-	-
TOTAL	281	92	32	1	2	408

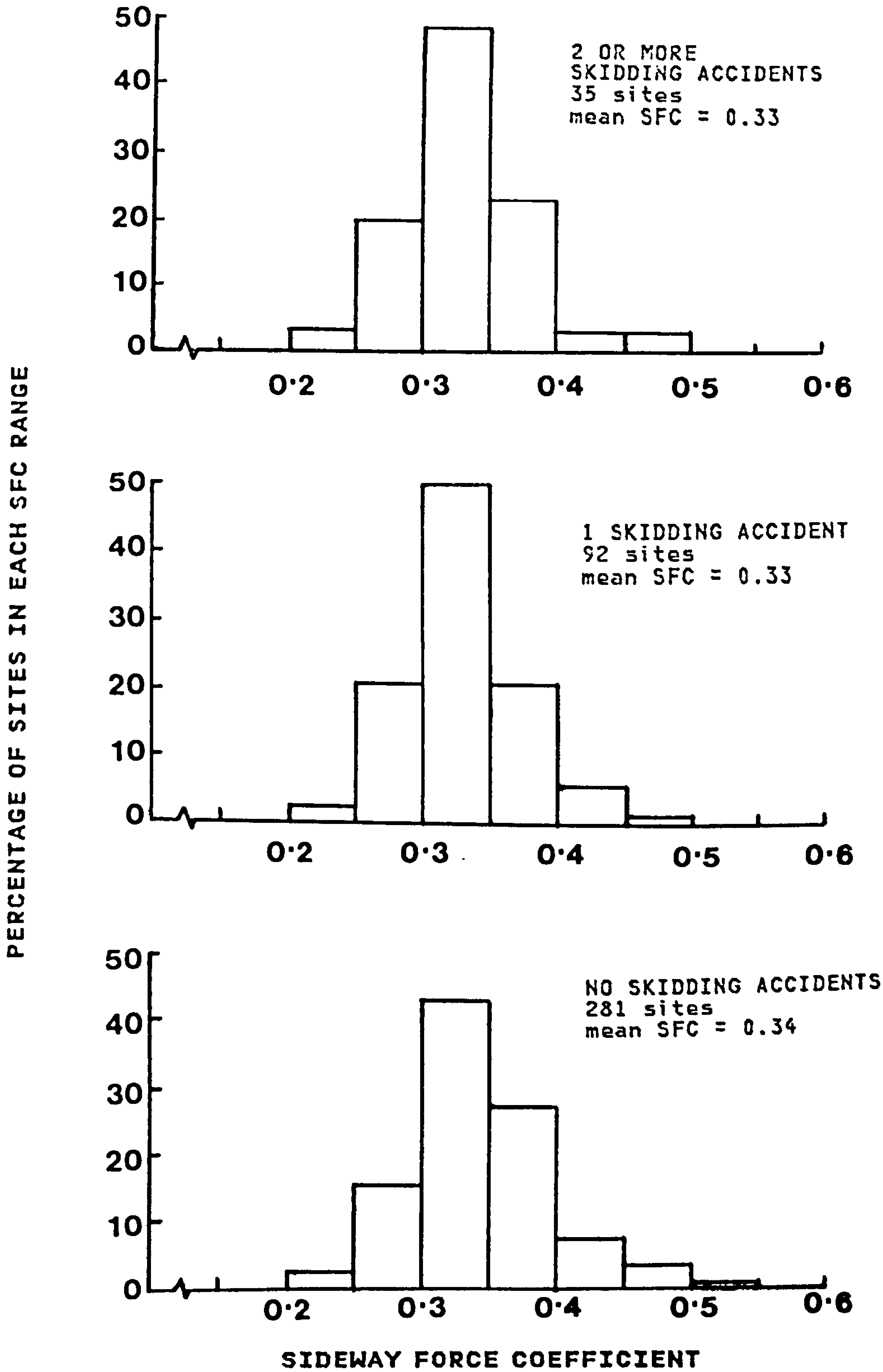


FIG. 5.3 comparison of SFC levels at skidding accident sites and other sites in London. (approaches to uncontrolled pedestrian crossings)

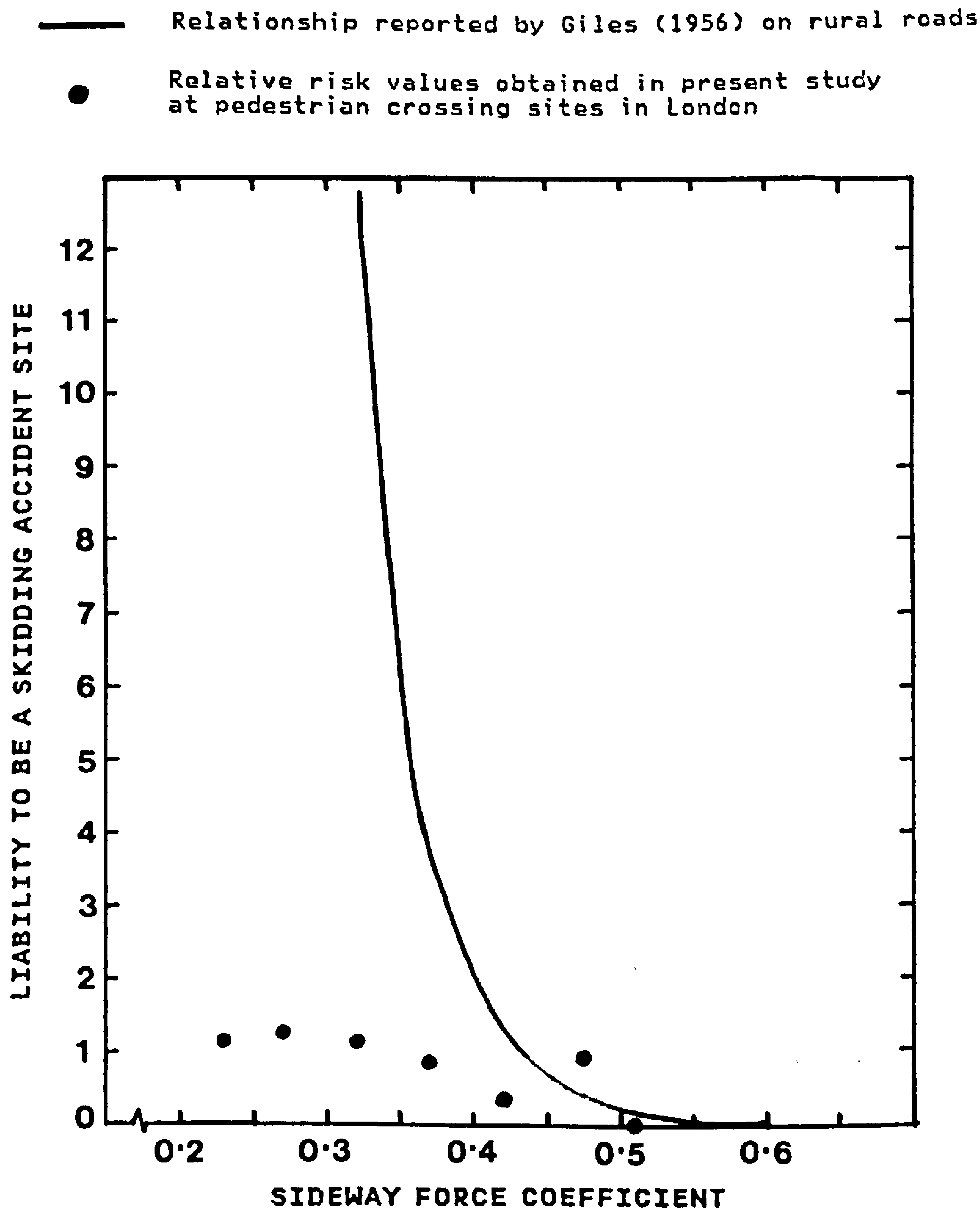


FIG. 5.4 <u>Sideway-force coefficient and the relative liability of a site to become the scene of repeated wet-road skidding accidents.</u>

obtained during the period when the accidents were occurring and for the random sites he used the means of the mid-summer and mid-winter values. Despite these differences it is clear that Giles's findings on the relationship between SFC and the relative liability of a site to become the scene of repeated wet-road skidding accidents do not apply to roads in London. A very low SFC at a site does increase the likelihood of skidding accidents occurring but by a substantially smaller extent than suggested by Giles's results.

It should also be noted that Giles's study of accidents was concerned mainly with skidding accident black spots. Such an approach is appropriate if only a limited programme of skid resistance improvements is envisaged because the identification and treatment of the black spots would then be the principal objective. However, the present study is concerned with assessing the overall potential for accident reduction and for this it is necessary to investigate the general relationship between SFC and accident rates, and to identify the characteristics of sites which will respond to an improvement in skid resistance.

5.3 MARSHALL COMMITTEE PROPOSALS

In 1970 the Marshall Committee on Highway Maintenance (13) proposed the set of target values shown in Table 5.6. They are derived from the Giles proposals but differ in a number of important respects. Site category D - 'proved sites' is omitted. The lowest category is C - 'other sites' (equivalent to Giles's 'easy sites') with a target SFC of 0.40. Category B - 'average sites' (Giles's 'general requirements') with a target SFC of 0.50 is more clearly defined and includes motorways, other high-speed roads and heavily-trafficked roads (including all Trunk and Principal roads) in urban areas. In category A - 'most difficult sites' the target SFC is reduced to 0.55, presumably in recognition of the difficulty of achieving the value of 0.60 suggested by Giles. The proposed standards are apparently based on no more substantiation than that provided by Giles.

TABLE 5.6

Target SFC values proposed by the Marshall Committee (13)

Category of Site	Type of Site	SFC	test speed (km/h)
A	Most difficult sites eg: (i) roundabouts (ii) bends with radius less than 150m on unrestricted roads (iii) gradients of 5% (1 in 20) or steeper or longer than 100m (iv) approaches to traffic signals on unrestricted roads	0.55	50
B	Average sites eg: (i) motorways and other high speed roads (i.e. speeds in excess of 95 km/h (60 mph)) (ii) trunk and principal roads and other roads with more than 2,000 vehicles per day in urban areas.	0.50 0.45 0.50	50 80 50
C	Other sites ie: Straight roads with easy gradients and curves, without junctions and free from any feature, such as mixed traffic, especially liable to create conditions of emergency	0.40	50

The omission of the 'proved sites' category appears to have been intended as a measure to improve the general level of skid resistance throughout the country. Compliance with the standards would ensure that no road had an SFC below 0.40. Compliance is technically feasible (as was shown in Chapter 4) but whether the cost of achieving it is justified is open to question. Giles included the 'proved sites' category, for which there is no minimum skid resistance requirement, because he recognised that there are sites at which the skid resistance may be low but the risk of skidding is minimal, for instance on many urban roads where traffic speeds are very low. Expenditure on improving the skid resistance at such sites would be wasteful because there would be little or no benefit in terms of accident savings.

The inclusion of all urban Principal roads in category B presents problems. On heavily-trafficked roads it is both difficult and expensive to maintain the target SFC of 0.50 and on a substantial proportion of urban Principal roads the SFC is well below that value. Table 5.7 shows the distribution of SFC values measured in 1979 at 227 one-hundred metre sections of Principal road in a typical London borough (Borough B). The sections were all at least 50 metres away from nodes (major intersections) and were all surfaced with hot-rolled asphalt (sites treated with anti-skid surfacing were not included in the survey). The site selection procedure is described in Section 6.3. It will be seen that the SFC at 225 of the sections was less than the required 0.50. Nevertheless, as Table 5.8 shows, at 176 of these 'low' SFC sections there were no wet-road accidents involving skidding in the five-year period 1977-81 and at 56 of the sections there were no wet-road accidents at all. Clearly, at many of these sites there is nothing to be gained by increasing the skid resistance to achieve compliance with the Marshall standards.

It is unfortunate that when the Marshall standards have been used in the courts in cases where there have been claims against the highway authority for compensation following a skidding accident they have on occasion been accepted as distinguishing between a 'safe' and an 'unsafe' condition. Thus a site in category B might be considered to be satisfactory if the SFC is 0.50 but dangerously slippery if it is 0.49. This is too literal an interpretation of the standards. Giles himself stressed that no simple dividing line can be established

TABLE 5.7

Distribution of average SFC values on 100-metre sections of Principal road in Borough B (hot-rolled asphalt surfacing)

SFC	FREQUENCY n	FREQUENCY %
0.23	1	0.4
0.24	-	-
0.25	4	1.8
0.26	1	0.4
0.27	1	0.4
0.28	5	2.2
0.29	5	2.2
0.30	8	3.5
0.31	8	3.5
0.32	17	7.5
0.33	13	5.7
0.34	19	8.4
0.35	17	7.5
0.36	18	7.9
0.37	16	7.0
0.38	22	9.7
0.39	15	6.6
0.40	15	6.6
0.41	12	5.3
0.42	13	5.7
0.43	4	1.8
0.44	4	1.8
0.45	3	1.3
0.46	2	0.9
0.47	-	-
0.48	1	0.4
0.49	1	0.4
0.50	1	0.4
0.51	-	-
0.52	1	0.4
TOTAL	227	100.0

TABLE 5.8

Wet-road accidents at sites with SFC below 0.50

NUMBER OF ACCIDENTS (1977-81)	NUMBER OF SITES: WET-ROAD ACCIDENTS	NUMBER OF SITES: WET-ROAD SKIDDING ACCIDENTS
0	56	176
1	45	36
2	34	11
3	29	1
4	18	1
5	12	-
6	9	-
7	7	-
8	5	-
9	5	-
10	1	-
11	2	-
17	1	-
22	1	-
TOTAL SITES	225	225
TOTAL ACCIDENTS	581	65

between a satisfactory and an unsatisfactory level of skid resistance. Moreover, the SFC test reproducibility is not sufficiently good to warrant such precise distinctions (see Section 3.4.3). Two SCRIM machines testing a section of road of SFC 0.50 would be expected to give SFC values differing by as much as 0.09 (on one occasion in 20) if the tests were conducted at the same time. The differences could be very much greater if the tests were at different times.

An important limitation of the Marshall standards is that within any one site category there is just one target SFC value. Clearly, individual sites within any one site category may have widely differing accident risks (as was illustrated in Table 5.8) and frictional demand levels will vary widely between sites. Salt and Szatkowski of TRRL have proposed a set of standards with a range of target values for each site category.

5.4 SALT AND SZATKOWSKI PROPOSALS

The most recent set of standards from TRRL was put forward by Salt and Szatkowski at a symposium (96) in 1972 and was published, with some changes, in TRRL report LR510 (9) in 1973. The three broad Marshall categories (now referred to as 'difficult', 'average' and 'easy') are retained and a fourth category ('very difficult') is added. The standards are much more flexible than the Marshall standards because they allow the engineer to select the appropriate target SFC value for an individual site (within limits defined for the particular site category) on the basis of his assessment of the relative accident risk (the 'risk rating'). The detailed site classifications and minimum SFC values proposed in LR510 are shown in Table 5.9. The earlier proposed standards were rather vague about the meaning of 'minimum SFC'. In LR510 it is defined clearly in terms of the mean summer SFC (the average of three readings taken during the months May to September) in a year of normal weather conditions.

It must be emphasised that Salt and Szatkowski have not published any detailed objective evidence (other than referring to Giles's early work) in support of their proposed minimum SFC values, in terms of skidding accident risk in relation to SFC and site classification. It

SITE	DEFINITION	MINIMUM SFC Risk Rating									
		1	2	3	4	5	6	7	8	9	10
A1 (v.difficult)	(i) Approaches to traffic signals on roads with a speed limit greater than 40 mile/h (64 km/h) (ii) Approaches to traffic signals, pedestrian crossings and similar hazards on main urban roads						0.55	0.60	0.65	0.70	0.75
A2 (difficult)	(i) Approaches to major junctions on roads carrying more than 250 commercial vehicles per lane per day (ii) Roundabouts and their approaches (iii) Bends with radius less than 150m or roads with a speed limit greater than 40 mile/h (64 km/h) (iv) Gradients of 5% or steeper, longer than 100m				0.45	0.50	0.55	0.60	0.65		
B (average)	Generally straight sections of and large radius curves on: (i) Motorways (ii) Trunk and principal roads (iii) Other roads carrying more than 250 commercial vehicles per lane per day	0.30	0.35	0.40	0.45	0.50	0.55				
C (easy)	(i) Generally straight sections of lightly trafficked roads (ii) Other roads where wet accidents are unlikely to be a problem	0.30	0.35	0.40	0.45						

TABLE 5.9 Minimum SFC values proposed by Salt and Szatkowski in LR510

must, therefore, be assumed that the proposed values (and site classifications) are not necessarily definitive and that they are are based on engineering judgement rather than on experimental findings. It must further be assumed that their applicability in urban areas will be subject to at least the same limitations as those inherent in Giles's original work.

For category A1(ii) sites, which include approaches to traffic signals, pedestrian crossings and similar hazards on main urban roads, minimum SFC values ranging from 0.55 to 0.75 are suggested, depending on the risk rating. In presenting the proposals at the TRRL symposium Salt acknowledged that these levels of SFC could not be achieved at such sites with conventional surfacing materials and it would, therefore, be necessary to use artificial aggregates such as calcined bauxite (as in the Shellgrip process).

Salt stated that category A sites represented only a very small proportion of the road length nationally and gave as an example a home county road network where only 0.1% of the road length fell into category A1. This may be true of a typical rural county but in London there are about 5,000 category A1 sites (including 1,500 light-controlled junctions, 750 pelican crossings and 2,500 zebra crossings) constituting 8% of the classified road network and 2% of the total road length. The cost of treating all these category A1 sites with Shellgrip would be about £25,000,000 (at 1983 prices) which is equivalent to about seven times the entire annual budget for resurfacing work on London's Principal roads. In fact, the GLC has already treated nearly 2,000 of the category A1 sites over a period of 17 years. At many of the remaining sites the accident rate is very low and there may be no economic justification for expenditure to improve the SFC to the minimum of 0.55 suggested in LR510.

In proposing a reduction in the target SFC value for motorways from a minimum of 0.50 in the Marshall standards to a minimum of 0.35 (later reduced to 0.30 in LR510) Salt argued that the reduction was justified because

(a) the recommended level of 0.50 was not often attained,

(b) despite the fact that SFC values were typically only about 0.35 the accident rates on motorways were relatively low,

(c) there were many sites where the lowest risk rating was appropriate.

A similar argument could be applied to urban roads in categories A1 and A2. At most of these sites it is very difficult, if not impossible, to maintain the proposed SFC levels with conventional materials, the average SFC level is very low and yet there are many sites where the reported accident rate is low. Clearly, there are some sites in these categories where the skidding accident risk is high and expenditure to attain a high skid resistance is fully justified. However, it could be argued that if a site has a low skid resistance but also has an accident rate which is demonstrably very low then it should be assigned an appropriately low risk rating. The full range of risk ratings (on the scale 1 to 10) and corresponding target SFC values (0.30 to 0.75) should be applicable to any site regardless of its category. Each site would then be considered on its merits without any constraints.

No detailed guidance on the assessment of risk rating is given in LR510 but it is suggested that the skidding accident potential of each site should be assessed from a consideration either of its accident record or of its characteristics (cambers, slopes, lengths of sight lines, surface water drainage, presence of mud or leaves, shadows from trees or buildings, etc.). It is suggested in LR510 that if none of this information is available the lowest risk rating in the appropriate site category should be used (originally the mid-point risk rating was suggested). Adopting this suggestion would result in lower criteria than the Marshall standards by 0.1 SFC for many of the difficult sites, 0.15 SFC for sites of average accident risk and 0.1 SFC for 'other' sites.

If a system of standards is to be adopted which requires the engineer to judge accident risk for each section of road within a network then it is important that a soundly-based assessment procedure should be developed. Methods of assessing relative accident risk are examined in Chapter 6.

CHAPTER 6

ASSESSMENT OF ACCIDENT RISK

6.1 INTRODUCTION

Examination of the past accident record at an individual site is the most obvious way of assessing the relative accident risk in order to determine whether a higher-than-average skid resistance is required. This approach has come in for some criticism because it implies that action should be taken at a site only after a significant number of accidents has occurred. It could be argued that this is too negative an approach and the emphasis should be on identifying potential accident sites and dealing with them before they become accident black spots. This is an appealing philosophy and consideration must be given to developing a system for identifying high-risk locations but it must be accepted that when funds are limited priority must be given to dealing with known accident black spots rather than potential ones. Furthermore, the assessment of accident potential can only be conjectural whereas the incidence of repeated accidents at a site is a firm indication of some deficiency at that site.

The financial consequences of making a wrong assessment of accident risk can be substantial. Consider, for example, a pedestrian crossing approach on an urban road. From Table 5.9 (extracted from LR510) it will be seen that it falls into category A1 (very difficult) where the risk ratings range from 6 to 10 with corresponding target SFC's from 0.55 to 0.75. The lower SFC might well be attainable with conventional surfacing materials at a modest cost but the higher level would require a very expensive surface treatment. If the engineer judged the site to be at the highest risk rating (10) whereas in reality it had a very low accident rate (corresponding to risk rating 6) then maintenance funds would have been wasted. Conversely, if it had been judged to be risk 6 instead of a true risk 10 then accidents are likely to occur which could have been prevented.

The simplest method of assessing the risk rating of an individual site is for a highway engineer to make a subjective assessment on the basis of a visual inspection. Most highway engineers are no doubt confident that they can reliably assess the relative accident risk in this way, using their engineering judgement and knowledge of local conditions. It is important to assess the validity of such assessments. Also, as in any form of subjective assessment, there will be differences between individual ratings and between ratings by the same person on different occasions and the effect of these differences must be considered.

An alternative method is to identify site features which have a significant influence on accident rates and then develop an objective rating system based on these features. Workers in the United States (97) have shown that it is possible to develop reliable accident prediction methods based on measurable site parameters such as traffic volume, vehicle speeds, roads width and skid resistance. This approach is investigated in some depth in the present study in Sect.6.3.

6.2 SUBJECTIVE ASSESSMENT

6.2.1 Risk rating study A

A group of 50 uncontrolled pedestrian crossings in two East London boroughs was selected for study. Four engineers (A, B, C, D) acted as raters and all 50 sites were rated on two occasions (several weeks apart) by each engineer. The raters were asked to assess the accident risk for all types of accident (not just skidding accidents) at each site on a scale 1 to 5.

1 - very low
2 - low
3 - average
4 - high
5 - very high

All the sites were within LR510 category A1 and so the five-point scale corresponds to ratings 6 to 10 in Table 5.9. All the engineers had a detailed knowledge of the roads in the two boroughs. They were asked to keep in mind a notional average crossing in those boroughs as a reference site. The assessments were made from a vehicle parked on the approach to each crossing to give a driver's eye view of the site.

Assessment of the risk rating of a site is a complex task because some of the relevant factors vary with time of day, weather conditions, etc. Individual on-site assessments will be made in the context of a given traffic volume, traffic composition, level of pedestrian activity, etc. In order to keep the assessment conditions constant all of the ratings in this study were made in off-peak daylight hours in good weather conditions but the raters were asked to make allowance in their assessment for the effects of varying conditions at other times and produce an overall risk rating for each site.

The location of each crossing was established in relation to the GLC accident location network and listings were obtained of all personal injury accidents in the appropriate nodes and links. The listings were examined to identify accidents occurring within 50 metres of each crossing in the years 1977-79. The accident total for each site is shown in Table 6.1 together with the two subjective risk ratings produced by each assessor.

The survey results were analysed to determine

- the variability in risk rating at the same site made by the same assessor on different occasions.
- the variability in risk ratings of the same site made by different assessors.
- the degree of correlation between risk rating and accident rate at each site.

The variability between pairs of ratings obtained by each assessor is analogous to test repeatability (k) as defined in Chapter 3 (Section 3.1). Similarly, the variation between assessors is equivalent to test reproducibility (K).

(i) <u>Variability in risk ratings made by the same assessor on different occasions.</u>

Generally ratings by the same assessor differ by no more than one point on the assumed 5-point scale. However, there are several instances where the ratings differ by 2 points and two instances (confined to rater C) where the difference is 3 points (4 cf. 1).

TABLE 6.1

Subjective risk ratings at pedestrian crossing sites in East London

site no.	A1	A2	B1	B2	C1	C2	D1	D2	mean rating	accident total
1	2	2	3	3	2	1	3	3	2.4	3
2	2	3	3	2	2	2	3	3	2.5	3
3	3	2	2	2	3	1	3	1	2.1	2
4	1	1	3	2	3	2	2	2	2.0	11
5	4	3	4	3	3	2	3	2	3.0	4
6	3	3	4	3	2	1	2	2	2.5	7
7	4	3	4	3	4	1	2	2	2.9	8
8	3	3	3	2	3	2	3	3	2.8	8
9	3	2	3	3	2	2	2	2	2.4	11
10	3	3	4	3	3	2	2	2	2.8	11
11	4	4	4	4	3	1	3	3	3.3	5
12	4	3	2	2	2	3	3	3	2.8	1
13	3	3	2	3	4	2	3	3	2.9	3
14	3	3	3	3	3	2	4	3	3.0	9
15	2	2	2	3	4	3	2	1	2.4	7
16	2	2	3	3	3	2	2	2	2.4	7
17	2	2	1	2	2	1	2	2	1.8	4
18	2	2	2	2	4	1	3	2	2.3	1
19	3	2	3	3	3	1	3	2	2.5	5
20	3	3	3	3	4	2	3	2	2.9	22
21	2	2	3	3	3	2	3	1	2.4	9
22	3	3	4	4	4	2	4	3	3.4	13
23	2	2	3	3	3	2	4	3	2.8	1
24	2	2	2	2	2	2	3	2	2.1	3
25	1	1	3	2	3	2	2	1	1.9	4
26	4	2	4	4	2	2	3	3	3.0	4
27	3	3	3	3	1	1	2	3	2.4	12
28	3	3	3	2	3	2	2	2	2.4	15
29	3	3	3	4	4	2	2	2	2.9	17
30	4	4	4	4	2	3	3	3	3.4	25
31	4	3	4	4	2	3	3	3	3.3	9
32	5	4	4	4	4	3	4	3	3.9	21
33	5	4	3	4	4	3	4	3	3.8	13
34	3	3	4	4	2	3	3	3	3.1	9
35	4	3	3	3	2	3	4	2	3.0	11
36	3	3	2	3	2	2	3	2	2.5	3
37	2	3	2	3	1	2	3	2	2.2	13
38	3	2	2	2	3	2	3	3	2.5	4
39	3	2	3	3	4	3	3	2	2.9	11
40	2	2	2	2	2	2	4	2	2.3	17
41	2	3	2	3	1	1	3	2	2.1	13
42	2	3	2	3	3	1	4	2	2.5	13
43	5	4	4	4	5	4	4	4	4.3	25
44	5	5	5	5	3	4	5	4	4.5	20
45	4	4	4	4	2	2	4	4	3.5	22
46	4	3	3	3	2	2	3	2	2.8	8
47	4	3	2	3	3	3	4	3	3.1	9
48	2	2	2	2	2	1	2	2	1.9	4
49	3	2	3	2	4	2	4	2	2.8	10
50	3	2	2	2	3	2	3	3	2.5	10

Repeatability - Assessor A = 1.4
Assessor B = 1.2
Assessor C = 2.5
Assessor D = 1.8

Reproducibility = 2.03

This implies that on the first occasion the rater in question considered the site to be more dangerous than the notional average for the area and on the second occasion he considered the same site to be much safer. The repeatability values shown in Table 6.1 reflect these differences; the k values for assessors A, B, and D are 1.4, 1.2 and 1.8 respectively, whilst the value for assessor C is 2.5. These results indicate that if engineering decisions are to be made on the basis of subjective assessment of accident risk there is a need to screen potential assessors for consistency in rating.

(ii) Variability in risk rating between different assessors.

As might have been expected there is greater variability between risk ratings made by different assessors compared with repeat assessments by one individual. Nevertheless, there is generally good agreement between assessors in rating sites at which the risk is judged to be either above average or below average. The variability is greatest for the average sites (i.e. sites with a risk rating of about 3). The reproducibility of the sites with mean risk rating between 2.5 and 3.5 is 2.22, whilst for sites above and below that range the reproducibility values are 1.87 and 2.08 respectively. The overall reproducibility of the assessments for all the sites is 2.03

(iii) Correlation between accident history and risk rating.

Whilst the results in the previous sections show that the repeatability and reproducibility of subjectively-assessed risk ratings are moderately good, it is of fundamental importance to establish whether the risk rating correlates with the actual accident rate. Consistency of risk rating is of little use if the risk rating is a poor predictor of accident risk. Table 6.2 shows the correlation coefficient, r, (and the associated probability levels) obtained when the accident total at each site was compared with the individual risk ratings and with the overall mean risk rating.

TABLE 6.2

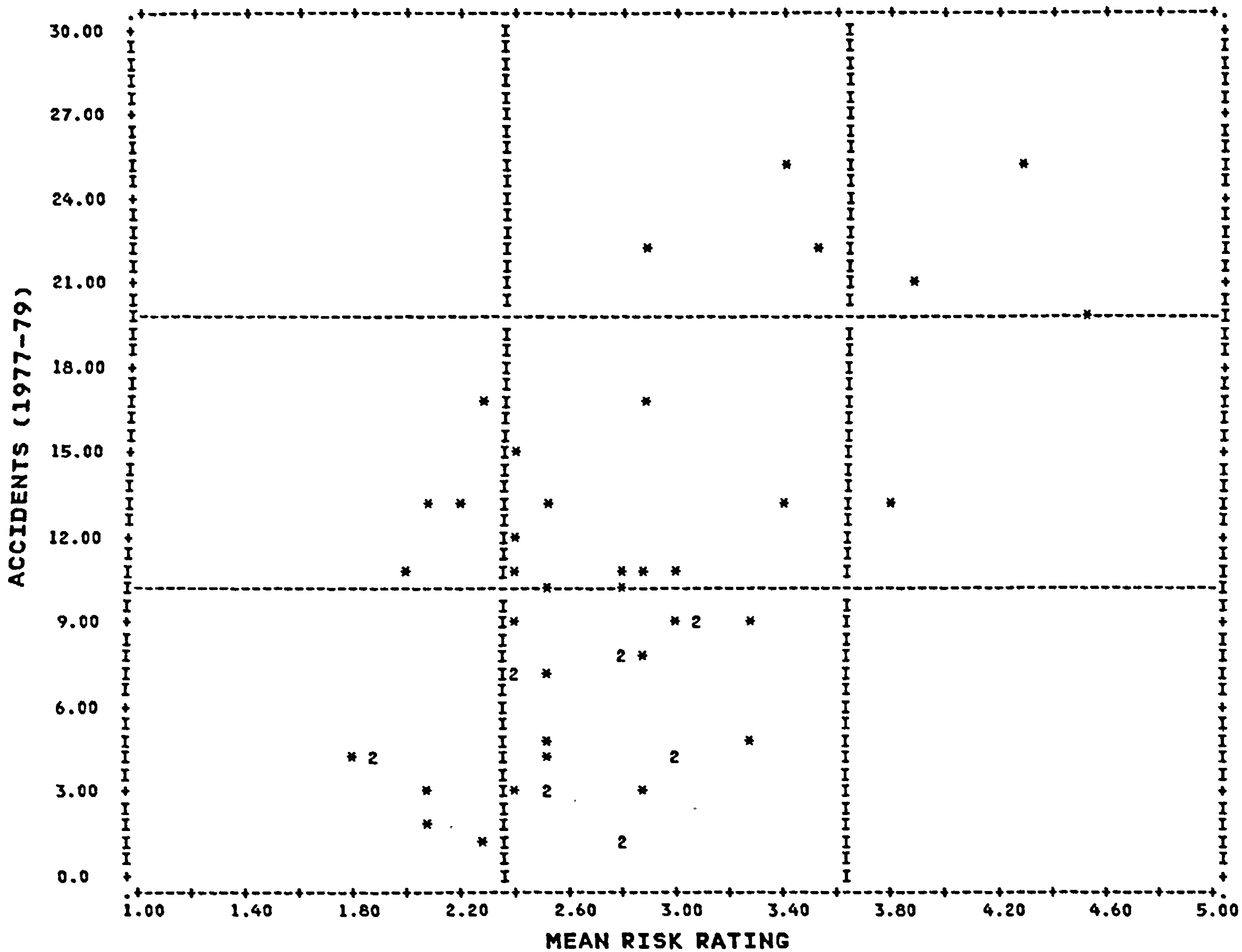
Correlation between risk rating and accident rate

Assessment	r value	probability level
A1 A2	0.40 0.56	0.002 <0.001
B1 B2	0.42 0.51	0.001 <0.001
C1 C2	0.18 0.45	0.106 0.001
D1 D2	0.32 0.32	0.012 0.012
mean	0.56	<0.001

The highest r value was obtained for accident total v. mean risk rating; the value of 0.56 indicates a high degree of correlation (significant at better than 0.001 probability). The highest individual r values were achieved by assessors A and B both of whom were consistently good (probabilities better than 0.002). Assessor D was consistently indifferent ($r = 0.32$ and probability = 0.012 for both sets of ratings). Assessor C was erratic; his first set of ratings was poor ($r = 0.18$, probability 0.106) but his second set was very good ($r = 0.45$, probability 0.001). Figure 6.1 shows total accidents plotted against mean risk rating. The strong positive correlation between the two variables is immediately apparent, indicating that the mean risk rating method is generally ranking sites in the correct order in terms of the accident history. The average number of accidents in the three years ranged from 1 to 25 with an average of 9.6 per site. It is interesting to note from the scattergram that, of the six sites with the highest accident totals, five were correctly identified as being above average risk and the seven sites with the highest risk ratings all had accident rates above average.

6.2.2 Risk rating study B.

The results of the previous survey showed that assessors could subjectively rank sites in order of accident risk with a moderate degree of reliability and consistency. The task of the assessors in study A was fairly simple because they were examining sites which were all in the same category (i.e. uncontrolled pedestrian crossings and



correlation (r) = 0.55708
r squared = 0.31033
significance = 0.00001
intercept = -7.17079
slope = 6.08078
no. of values = 50

FIG. 6.1 Mean subjective risk rating v. accident rate (pedestrian crossing sites in London) their approaches) and merely had to judge the relative accident rate on a five-point scale. A further study was conducted on a large number of sites representing a wide range of site categories and conditions (ranging from pedestrian crossings in busy shopping centres to quiet residential areas). The sites were a group of 268 one-hundred metre sections of road in a typical London borough (Borough B). The sections were all at least 50 metres from nodes. The site selection procedure is described in Section 6.3.2.

In this survey only one assessor was used (the author - assessor A in the first study). The task was to examine each site and to assign risk ratings based on the subjectively-predicted number of accidents in a given period (as distinct from accidents per million vehicle kilometres). For the first twenty or so sites additional ratings were assigned for skidding accident and wet-road accident risk but it was found that in every case the additional ratings were the same as for the general accident risk rating and so the separate assessments were discontinued. In terms of the LR510 site classifications the sections were mostly in Category B, 'average' (with the risk rating to be selected from the range 1 to 6). Five of the sections were in Category A2, 'difficult' (risk rating range 4 to 8) and seventeen were in Category A1, 'very difficult' (risk rating range 6 to 10). Each site was assesssed on only one occasion but two risk rating values were assigned. The first was coded RRLR and was strictly in conformity with the limited ranges in LR510. For the second rating, coded RRY, the full range of risk ratings, 1 to 10, was available for each site regardless of the site category and without the constraints imposed by LR510. For instance, a section which included a pedestrian crossing is in Category A2 of LR510 with a minimum risk rating of 6 but if it was judged to be low risk, perhaps because of very slow-moving or infrequent vehicle movements then it would be assigned an appropriately low rating.

Listings were obtained of all injury accidents in each 100-metre section in the five-year period 1977-81. Table 1 in Appendix D shows the two risk ratings for each section together with the numbers of wet-road accidents - coded WETACC, wet-road skidding accidents - WETSKD and accidents of all types - TOTACC (and also a number of other parameters which are discussed in Section 6.3).

Bivariate correlation analysis (using SPSS) for risk rating against each type of accident produced the correlation coefficients shown in Table 6.3.

TABLE 6.3

Correlation between subjective risk rating and accident rate (268 sections)

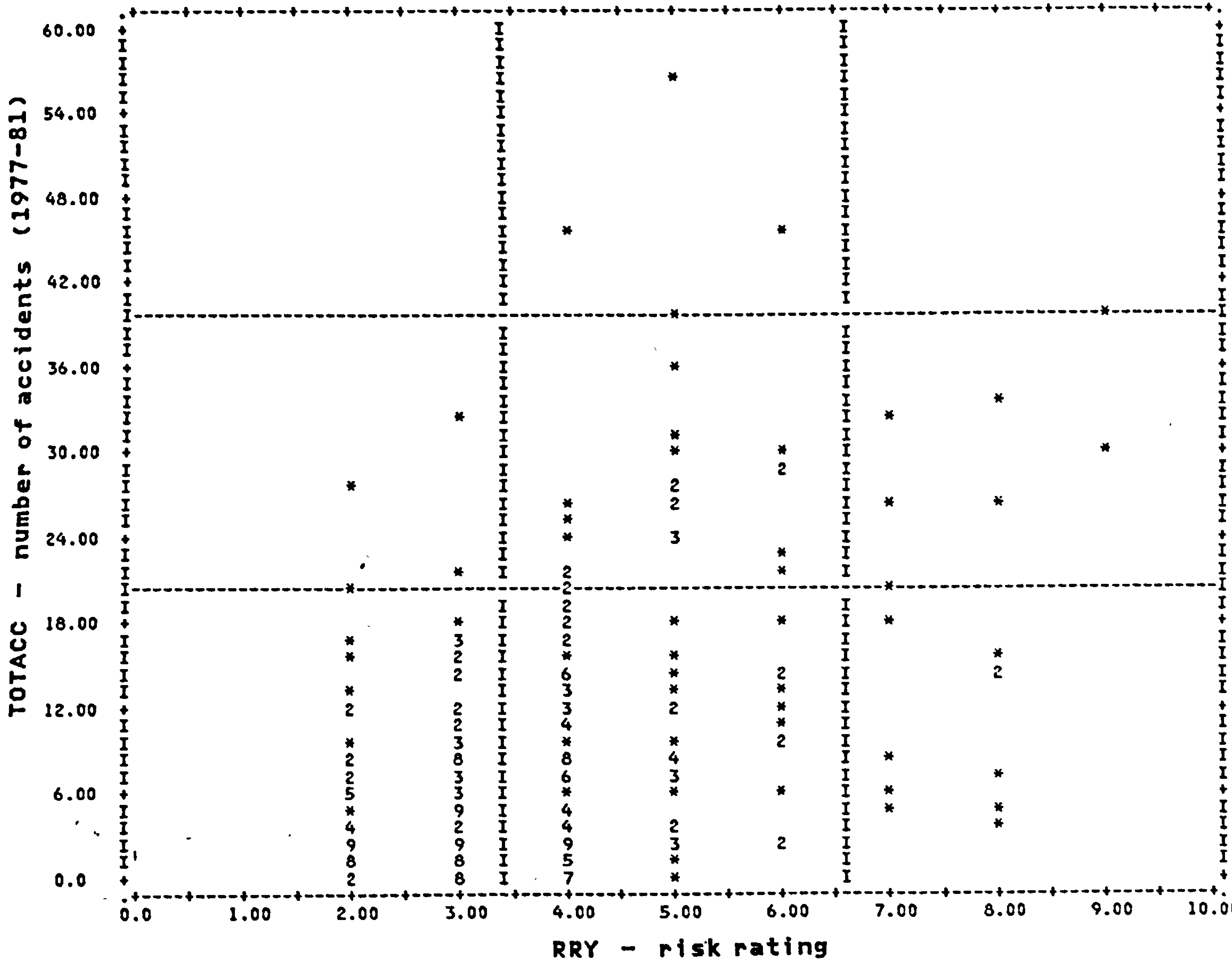
accident parameter	r value (and probability) RRY	RRLR
TOTACC	0.444 (p<0.001)	0.424 (p<0.001)
WETACC	0.276 (p<0.001)	0.258 (p<0.001)
WETSKD	0.026 (p=0.339)	0.030 (p=0.314)

For RRY the highest r value (i.e. the best correlation) was obtained with total accidents. The r value of 0.444 indicates a highly significant correlation (at probability better than 0.001). The r value is slightly lower than that obtained for the equivalent correlation with the same assessor in survey A but, since the sample size is greater (268 compared with 50), the associated probability is similar.

The r value for RRY v. wet-road accidents is lower but still highly significant (r = 0.276, probability better than 0.001).

The r value for RRY v. wet-road skidding accidents was only 0.026 which indicates virtually no association between risk rating and skidding rate. This is also an indication that in urban conditions it is very difficult to make reliable predictions about the incidence of skidding.

The r values for RRLR v. total accidents and wet-road accidents were slightly lower than the equivalent values for RRY, suggesting that there may be some benefit in removing the risk rating limits within each site category in LR510. The r value for RRLR v. wet skidding accidents was slightly higher than the equivalent value for RRY but since both were close to zero the difference is unlikely to be of any practical significance.



correlation (r) = 0.44364
r squared = 0.19682
significance < 0.00001
intercept = -1.34987
slope = 2.86274
no. of values = 268

FIG. 6.2 Risk rating v. accident total (sections of road in Borough B)

Figure 6.2 shows RRY values plotted against total accidents. Although there is a strong positive correlation between the two variables there is considerable scatter and it is evident that a number of high-accident sites have not been recognised as such and have been assigned low risk ratings. Clearly, the subjective assessment of accident risk is far from satisfactory when applied to a wide range of sites and cannot be recommended as a basis for identifying high risk sites or for defining target skid resistance values.

6.3 OBJECTIVE ASSESSMENT

6.3.1 Introduction.

A study was carried out with the object of identifying those factors which have a significant effect on accident rates, particularly wet-road accidents and wet-road skidding accidents, and which could be used to define the risk rating of an individual site.

6.3.2 Site selection

The sites were all 100-metre sections of Principal road in Borough B. This borough was selected for study because it is in many ways a typical London borough and encompasses a wide range of localities, road types and traffic configurations. The localities from which the study sections were drawn ranged from busy shopping and commercial centres to quiet residential areas and public open spaces. The standard section length of 100 metres was chosen because it was small enough to give reasonably uniform site conditions but large enough to provide sufficient numbers of accidents in order to define meaningful accident rates. Furthermore, a computer program was available which could conveniently produce accident totals in 100 metre sub-sections within each link.

There are 53.4 km of Principal road in Borough B (constituting 61% of the classified road length in the borough) all of which was considered for inclusion in the study. It was decided to exclude nodal areas (the major intersections between classified roads) because the complex nature of the road-user interactions at these points might mask the effects of many of the factors being studied. Sections of road were also excluded where there had been major changes during the five-year accident study period which could have altered the accident rate (e.g. major traffic management schemes or the application of anti-skid surfacing). The nodal area is the centre point of the junction and the area within 50 metres of it. Ordnance survey maps of scale 1:1250 were obtained and the nodal areas were marked on them. The study sections were defined on the maps by measuring 100-metre lengths starting from the edge of each node area and working along the links. The residual portion at the end of each link was discarded. This procedure produced 268 sections for further study. Each section was coded in terms of the link reference (6 digits) and the chainage (in metres) of the start of the section.

6.3.3 Site parameters

The parameters considered for each site were in nine broad categories :-

- ROADSIDE LAND USE (shops, residential, etc.)
- SPECIFIC POTENTIAL HAZARD FEATURES AT ROADSIDE (e.g. bus stops, public houses)
- ROAD JUNCTIONS (and vehicular access points)
- PEDESTRIAN CROSSINGS
- GEOMETRICAL AND TRAFFIC MANAGEMENT FEATURES (width, gradient, bends, bus lanes, etc.)
- RISK RATING (SUBJECTIVE)
- TRAFFIC FLOW
- SKID RESISTANCE
- ACCIDENTS

One additional parameter that would have been desirable is some measure of vehicle speeds at each site but it was not practicable to obtain this information for a sufficient number of sites. This is probably not an important omission because all the sections in the study group (and the whole of Borough B) have a 30 mile/h speed limit and subjective observations suggest that the variation in speed between sections is not great.

Each site was inspected on foot to determine most of the physical parameters and the risk ratings. Large-scale maps were used to measure gradients (from spot heights) and bends. The remaining information (traffic flows, skid resistance, accident rates) was obtained from GLC records.

(i) Roadside land use

The nature of the roadside development is likely to have an important bearing on road-user interactions and hence on accident rates. For instance, in a shopping centre there is likely to be a very high rate of pedestrian flow across the road, perhaps at random points, leading to a high incidence of emergency braking.

Nine categories of roadside land use were defined :-

1 Housing - coded HOUSNG
2 Shops (including small commercial premises within a shopping area) - SHOPS
3 Commercial (office buildings, garages, etc.) - COMM
4 Industrial (factories, warehouses, vehicle depots) - INDUST
5 Public building (town hall, library, church, etc.) - PUBLBG
6 School (and other academic institutions) - SCHOOL
7 Open space (park, large private grounds) - OPENSP
8 Vacant plot - VACANT
9 Other - OTHER

Many sections were found to be a mixture of several categories of land use. The proportion of the frontage represented by each category was recorded (to the nearest 10%).

(ii) Roadside hazard features

The presence was recorded of three specific roadside features which could generate sudden conflicts :-

- bus stops
- garages
- public houses

(iii) Road junctions and other vehicular accesses

Although the most important junctions (i.e. the intersections between classified roads) were excluded from the study group, the majority of the junctions remained and constitute major conflict areas. As was shown in Chapter 2 over 40% of all accidents in London are at non-nodal junctions.

The road junctions were classified into two groups :-

- T or Y junctions (coded TJCT)
- crossroads or staggered junctions (coded XRD)

They were further sub-divided on the basis of the estimated total daily vehicle flow on the minor road(s).

1 - 100	(code suffix 1)
101 - 1000	(code suffix 2)
1001 - 5000	(code suffix 3)
above 5000	(code suffix 4)

Similarly, private acccess roads and drives were classified according to estimated daily vehicle flow :-

1 - 2	(ACCSS1)
3 - 50	(ACCSS2)
51 - 100	(ACCSS3)
above 100	(ACCSS4)

At the data processing stage six further parameters were computed :-

TJCT = TCT1 + TJCT2 + TJCT3 + TJCT4

XRD = XRD1 + XRD2 + XRD3 + XRD4

MINACC = ACCSS1 + ACCSS2

MAJACC = ACCSS3 + ACCSS4

ACCESS = MINACC + MAJACC

JCT = TJCT + XRD + MAJACC

(iv) <u>Pedestrian crossings</u>

These are likely to be major hazard points. They were recorded as either Zebra crossings (uncontrolled) or Pelican crossings (light-controlled).

(v) Geometrical and traffic management features

The features recorded were:-

- road width (to the nearest metre)
- bus lane
- one-way or two-way flow
- gradient (if significant) to the nearest 1%
- bends

Some difficulty was experienced in quantifying a few of the bends. In general, a bend was defined in terms of the angle of intersection (in degrees) of the tangents to the centre of the road at the start and end of each section. Where there is a double bend this method is inappropriate; treating the double bend as two separate bends and adding the results was found to give a misleading high value since drivers tend to 'straighten out' such bends. It was decided that in these cases (only 4 out of 268) only the lower radius bend would be recorded.

(vi) Subjective risk rating

As described in Section 6.2, two subjective assessments of relative accident risk (coded RRLR and RRY) were made at each site, on a scale 1 to 10.

(vii) Traffic flow

Estimates of total daily vehicle flow along each section were obtained from GLC traffic survey records (TRAFF).

(viii) Skid resistance

Measurements of skid resistance made during the routine monitor of GLC roads in 1979 were used. The SCRIM measurements in Borough B were all made on the same date and so the values obtained for each study section are directly comparable. The SCRIM values were all adjusted for seasonal variation (see Section 3.4) and multiplied by the SCRIM index (0.0078) to give a best-estimate mean summer SFC. The mean and standard deviation of the 10 SFC readings in each section were calculated.

(ix) Accident data

Accident information for the 5-year period 1977-81 was extracted from ACCSTATS to determine for each section the number of

- wet-road skidding accidents (WETSKD)
- wet-road accidents (WETACC)
- accidents of all types (TOTACC)

Additional computed accident parameters were :-

- accidents per million vehicle kilometres (ACCRAT)
- wet-road accidents per million vehicle kilometres (WETRAT)
- wet-road skidding accidents per million vehicle kilometres (SKRAT)
- percentage wet (PCWET)
- percentage of wet-road accidents involving skidding (PCSKID)
- excess wet-road accidents - the actual number of wet-road accidents minus the expected number estimated on the basis of the dry-road number and assuming an expected 25% of accidents in the wet (i.e. one wet-road accident would be expected for every three accidents occurring in the dry). (XSWET)

6.3.4 Site data.

The detailed information on each of the 268 sections is shown in coded form in Table 1 of Appendix D.

6.3.5 Data analysis.

Much of the statistical analysis was carried out using SPSS programs, in particular the PEARSON CORR (i.e. Pearson correlation coefficient, r), T-TEST and REGRESSION procedures.

The PEARSON CORR program was used to generate arrays of correlation coefficients to establish the degree of linear correlation between pairs of variables. For a sample size of 268 an r value of 0.101 or more indicates a significant correlation (at better than 0.05 probability) and a value of 0.141 or more indicates a highly significant correlation (better than 0.01 probability). The complete arrays of correlation coefficients are to be found in Table 2 of Appendix D.

The T-TEST procedure was used to establish whether the difference in mean between two sub-groups is significant. The conventional t-test requires that the two groups should have equal variance. Where variances are found to be significantly different SPSS uses a modified t-test. The standard error values calculated as part of the t-test procedure give an indication of the confidence limits for each group mean.

The REGRESSION procedure was used to develop multi-variable linear regression equations with a selected accident parameter as the dependent variable and site parameters as predictor variables. The procedure involves the use of a stepwise method of introducing additional variables into the regression equation in descending order of their ability to additionally explain variance in the dependent variable. One of the assumptions in regression anaysis is that the predictor variables are independent. Clearly there is an interaction between some of the variables used in this study (e.g. the roadside land-use categories). Whilst not necessarily invalidating any regression equations obtained this does make it impossible to define reliable confidence limits about any predictions.

A. Effect of traffic volume on accident rates

A strong correlation ($r = 0.449$, $r^2 = 0.202$, $p < 0.001$) was found between total accidents in the five-year study period (TOTACC) and traffic volume (TRAFF, average daily flow in thousands) with the linear regression equation

$$\text{TOTACC} = 0.489\ (\text{TRAFF}) - 2.126$$

Similarly, for wet-road accidents

$$\text{WETACC} = 0.098\ (\text{TRAFF}) + 0.236$$

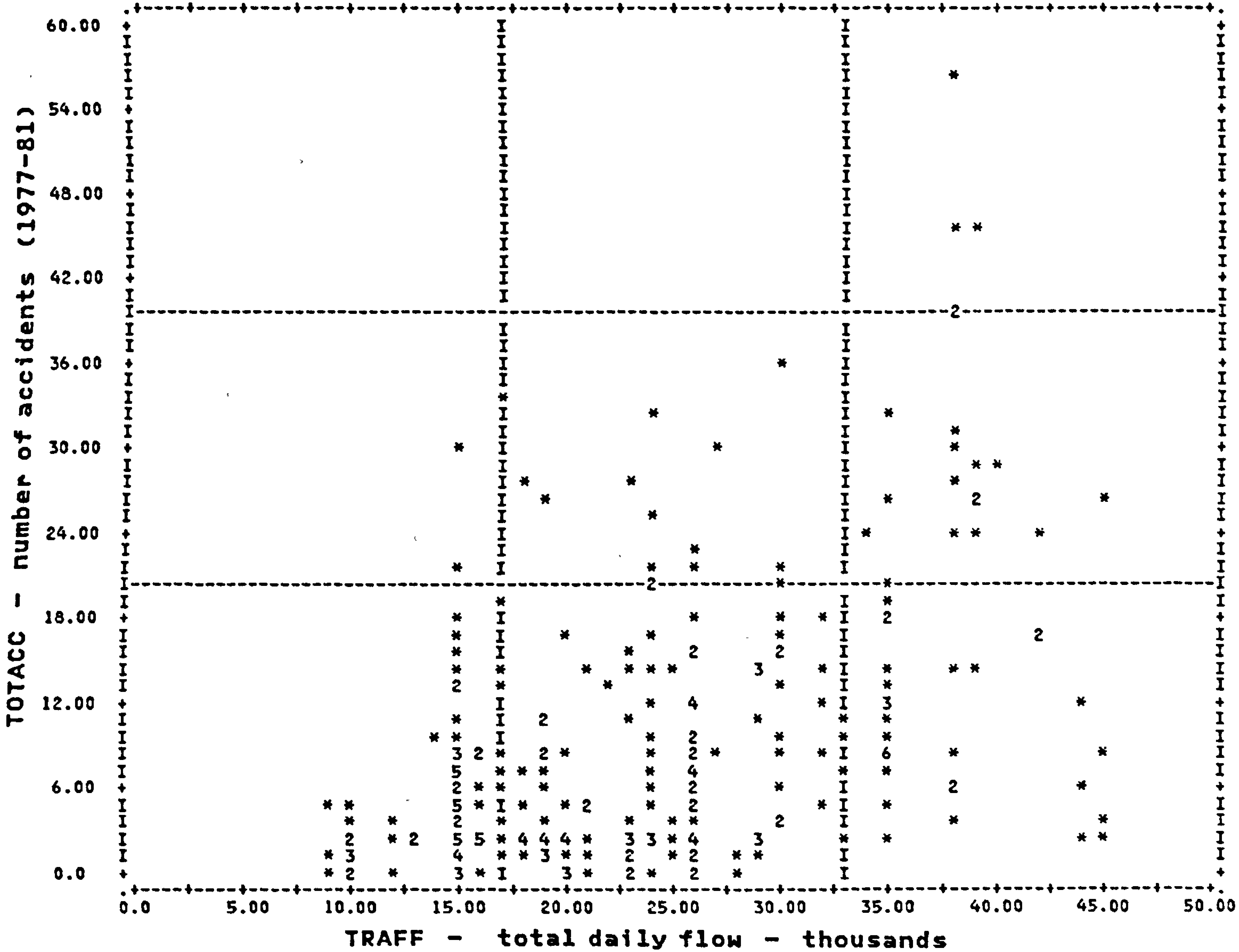
$$(r = 0.297,\ r^2 = 0.088,\ p < 0.001)$$

and for wet-road skidding accidents

$$WETSKD = 0.010\ (TRAFF) + 0.020$$
$$(r = 0.150,\ r^2 = 0.022,\ p = 0.007)$$

It is interesting to note that the r values for traffic volume v. total, wet-road and wet-road skidding accidents are all higher than the equivalent values obtained in Section 6.2 for risk rating (RRLR and RRY) v. accidents. This suggests that traffic volume alone is better than a subjectively-assessed risk rating as a predictor of relative accident numbers. However, as Figure 6.3 shows, the relationship between traffic volume and accident numbers is not a precise one. The r^2 value of 0.202 obtained for the traffic v. total accidents equation indicates that only 20% of the variation in accident totals is accounted for by variation in traffic volume. The remaining 80% is due to other factors. In the case of wet-road skidding accidents only 2% of the variation is attributable to variation in traffic volume.

Some non-linear models were examined for the relationship between traffic volume and number of accidents by performing a linear regression analysis on transformations of the traffic parameter, viz. $(TRAFF)^2$, $(1/TRAFF)$ and $\log(TRAFF)$ but all gave lower r^2 values than TRAFF.



correlation (r) = 0.44929
r squared = 0.20186
significance < 0.00001
intercept = -2.12614
slope = 0.48897
no. of values = 268

FIG. 6.3 Traffic volume v. accident total

B. Effect of roadside land use

From Table 6.4 it will be seen that the predominant land-use categories in Borough B are Housing, Shops, Commercial and Open Space which together occupy 90.3% of the total frontage.

TABLE 6.4

Roadside land use distribution

CATEGORY	%
Housing	53.4
Shops	15.3
Commercial	11.9
Open space	9.7
Public building	5.0
School	1.8
Industrial	1.6
Vacant plot	1.2
Other	0.1
TOTAL	100.0

Table 6.5 shows that the nature of the roadside land use has a considerable effect on accident rates. Accident totals in shopping areas are double the rate for other areas (difference significant at better than 0.001 probability). This clearly reflects the high conflict levels in shopping areas due to increased pedestrian activity and vehicles stopping and starting, etc. Accident totals are somewhat higher in commercial areas (but the difference is not significant) and very much lower in purely residential localities. Areas of open space also have a lower accident rate but because the number of such sections in the sample is small (only 7) the difference is not shown to be statistically significant.

TABLE 6.5

Comparison of accident rates for main land use categories

COMPARISON	NO. OF SECTIONS	MEAN ACC TOTAL	STD. ERROR OF MEAN	SIGNIFICANCE (p) OF DIFFERENCE BETW. MEANS
SHOPS 20% + SHOPS below 20%	77 191	15.40 7.46	1.32 0.55	< 0.001
HOUSNG 100% HOUSNG below 100%	63 205	5.54 11.03	0.82 0.70	< 0.001
COMM 20% + COMM below 20%	78 190	10.63 9.37	1.15 0.68	0.332
OPENSP 100% OPENSP below 100%	7 261	5.86 9.84	3.61 0.59	0.279
ALL SITES	268	9.74	0.59	-

Expressed in terms of traffic flow the mean accident rates are :-

SHOPPING AREAS	-	3.08	accidents/million	vehicle	km	
RESIDENTIAL AREAS	-	1.45	"	"	"	"
COMMERCIAL AREAS	-	2.20	"	"	"	"
OPEN SPACE	-	1.59	"	"	"	"
OVERALL	-	2.14	"	"	"	"

Table 6.6 shows the degree of correlation between accident numbers (TOTACC, WETACC, WETSKD) and the various categories of land use. The highest correlation is found between total accidents and proportion of shops. The r value of 0.494 indicates a highly significant correlation and is actually higher than the value obtained for traffic volume and total accidents. This implies that the proportion of shops is the better predictor of relative accident numbers. However, there is a strong correlation between traffic volume and proportion of shops ($r = 0.268$, $p < 0.001$), i.e. shops are more likely to be found on the more heavily-trafficked roads.

- - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - -

	TOTACC	WETACC	WETSKD	ACCRAT	WETRAT	PCWET	PCSKID	XSWET	TRAFF
HOUSNG	-0.3214 (268) P=0.000	-0.1927 (268) P=0.001	-0.1135 (268) P=0.032	-0.2095 (268) P=0.000	-0.0713 (268) P=0.122	0.0473 (268) P=0.221	-0.1102 (268) P=0.036	0.1078 (268) P=0.039	-0.3720 (268) P=0.000
SHOPS	0.4937 (268) P=0.000	0.3060 (268) P=0.000	0.0792 (268) P=0.098	0.3797 (268) P=0.000	0.1761 (268) P=0.002	-0.0957 (268) P=0.059	0.0219 (268) P=0.360	-0.1505 (268) P=0.007	0.2680 (268) P=0.000
COMM	0.0478 (268) P=0.218	0.0203 (268) P=0.370	-0.0047 (268) P=0.469	0.0235 (268) P=0.351	-0.0166 (268) P=0.394	-0.0233 (268) P=0.352	0.0013 (268) P=0.492	-0.0284 (268) P=0.322	0.1570 (268) P=0.005
INDUST	0.0398 (268) P=0.258	-0.0187 (268) P=0.380	-0.0302 (268) P=0.311	-0.0055 (268) P=0.464	-0.0437 (268) P=0.238	-0.0240 (268) P=0.348	0.0017 (268) P=0.489	-0.0768 (268) P=0.105	0.0603 (268) P=0.163
PUBLBG	0.0690 (268) P=0.130	0.0369 (268) P=0.274	0.0645 (268) P=0.146	0.0150 (268) P=0.403	0.0025 (268) P=0.483	0.0246 (268) P=0.344	0.0736 (268) P=0.115	-0.0293 (268) P=0.314	0.2192 (268) P=0.000
SCHOOL	-0.1013 (268) P=0.049	-0.1123 (268) P=0.033	-0.0384 (268) P=0.266	-0.0653 (268) P=0.144	-0.0837 (268) P=0.086	-0.0407 (268) P=0.253	-0.0193 (268) P=0.377	-0.0428 (268) P=0.242	-0.0892 (268) P=0.073
OPENSP	-0.0985 (268) P=0.054	-0.0426 (268) P=0.244	0.0570 (268) P=0.176	-0.1206 (268) P=0.024	-0.0640 (268) P=0.148	0.0589 (268) P=0.168	0.1038 (268) P=0.045	0.0575 (268) P=0.174	0.0872 (268) P=0.077
VACANT	0.0393 (268) P=0.261	0.0546 (268) P=0.187	0.1022 (268) P=0.047	0.1067 (268) P=0.041	0.1224 (268) P=0.023	-0.0075 (268) P=0.451	0.0481 (268) P=0.216	0.0330 (268) P=0.295	-0.0710 (268) P=0.123
OTHER	0.0853 (268) P=0.082	0.1054 (268) P=0.042	0.1020 (268) P=0.048	0.0576 (268) P=0.174	0.0475 (268) P=0.219	0.0204 (268) P=0.369	0.1342 (268) P=0.014	0.0523 (268) P=0.197	0.0723 (268) P=0.119

(COEFFICIENT / (CASES) / SIGNIFICANCE)

Table 6.6 Correlation between accident rate and land use

The multiple regression equation for traffic volume and proportion of shops against total accidents is :-

$$TOTACC = 0.150\ (SHOPS) + 0.372\ (TRAFF) - 1.570$$
$$(r^2 = 0.352)$$

Thus, traffic volume and proportion of shops together explain 35% of the variation in total accidents, compared with 20% explained by traffic volume alone.

There is a strong negative correlation between proportion of housing and accident numbers, i.e. accident rates are lower in residential areas, but adding HOUSNG to the regression gives virtually no improvement in r^2.

$$TOTACC = 0.156\ (SHOPS) + 0.381\ (TRAFF) + 0.084\ (HOUSNG) - 2.322$$
$$(r^2 = 0.353)$$

The lack of improvement in the r^2 value is probably due to the fact that there is a strong negative correlation between proportions of housing and shops ($r = -0.321$) and so the parameter SHOPS has to a large extent accounted for variations due to HOUSNG.

Inclusion of all the remaining land use categories in the regression analysis gives an increase of only 0.007 in the r^2 value and it must, therefore, be concluded that the proportion of shops is the only land-use parameter worth including in a regression equation.

$$\begin{aligned} TOTACC = \ & 0.162\ (SHOPS) + 0.390\ (TRAFF) + 0.121\ (VACANT) \\ & + 0.019\ (HOUSNG) + 0.014\ (COMM) + 0.111\ (OTHER) \\ & + 0.016\ (INDUST) - 0.011\ (SCHOOL) - 3.564 \end{aligned}$$

$$(r^2 = 0.360)$$

(PUBLBG and OPENSP rejected because they increase r^2 by less than 0.00001)

C. Effect of junctions

Junctions are important conflict areas. It was shown in Chapter 2 (Section 2.2.4) that 70% of all accidents in London in 1980 were at or within twenty metres of a junction. Table 6.7 shows that the mean accident total at the 189 sections containing junctions (including major private access roads) is more than double the total at the non-junction sections (difference significant at better than 0.001 probability). Sections with minor private accesses have significantly lower accident totals than the other sections but this is really a consequence of the fact that these accesses (mainly residential drives) are associated with residential areas where, as has already been shown, accident rates are generally low.

The addition of the parameter JCT (total number of junctions including major private accesses) to the regression along with TRAFF (traffic volume) and SHOPS (proportion of frontage occupied by shops) gives the equation :-

$$TOTACC = 0.139\ (SHOPS) + 0.362\ (TRAFF) + 1.304\ (JCT) - 2.844$$
$$(r^2 = 0.376)$$

Replacing JCT with TJCT, XRD, MINACC and MAJACC in the regression analysis gives an r^2 value of 0.387, an increase of only 0.011.

TABLE 6.7

Comparison of accident rates at junction and non-junction sections

COMPARISON		NO. OF SECTIONS	MEAN ACC. TOTAL	STD. ERROR OF MEAN	SIGNIFICANCE OF DIFFERENCE BETW. MEANS
JCT	= 0 = 1+	79 189	5.44 11.53	0.78 0.72	< 0.001
TJCT	= 0 = 1+	105 163	7.10 11.44	0.82 0.78	< 0.001
TJCT1	= 0 = 1+	250 18	9.64 11.11	0.62 1.53	0.531
TJCT2	= 0 = 1+	118 150	7.68 11.36	0.78 0.82	0.002
TJCT3	= 0 = 1+	258 10	9.55 14.50	0.59 3.15	0.110
XRD	= 0 = 1+	250 18	9.30 15.83	0.58 2.93	0.005
XRD1	= 0 = 1+	267 1	9.60 4.00	0.59 -	-
XRD2	= 0 = 1+	259 9	9.51 16.44	0.58 5.23	0.224
XRD3	= 0 = 1+	261 7	9.69 11.43	0.60 2.12	0.638
XRD4	= 0 = 1+	265 3	9.63 19.67	0.58 8.88	0.071
ACCESS	= 0 = 1+	106 162	11.49 8.59	1.09 0.65	0.023
MINACC	= 0 = 1+	120 148	11.78 8.08	1.04 0.62	0.002
MAJACC	= 0 = 1+	226 42	9.52 10.90	0.62 1.68	0.392
ACCSS1	= 0 = 1+	216 52	11.07 4.21	0.66 0.91	< 0.001
ACCSS2	= 0 = 1+	154 114	9.97 9.43	0.87 0.72	0.635
ACCSS3	= 0 = 1+	251 17	9.46 12.59	0.59 3.09	0.347
ACCSS4	= 0 = 1+	242 26	9.73 9.85	0.62 1.83	0.952

D. Effect of pedestrian crossings

Table 6.8 shows that sections with pedestrian crossings (either pelican or zebra) have about twice as many accidents as other sections. However, inclusion of the parameter PEDX in the regression equation gives only a modest increase in the r^2 value.

$$TOTACC = 0.131\ (SHOPS) + 0.361\ (TRAFF) + 1.237\ (JCT) + 2.436\ (PEDX) - 2.895$$

$$(r^2 = 0.382)$$

Thus, although accident rates are undoubtedly higher at or near pedestrian crossings, this may well result, at least in part, from the presence of other features such as junctions or shops which are commonly found in the vicinity of pedestrian crossings. Furthermore, crossings tend to be sited on the more heavily-trafficked roads.

TABLE 6.8

Effect of presence of pedestrian crossing on accident rate

COMPARISON	NO. OF SECTIONS	MEAN ACCIDENT TOTAL	ST. ERROR OF MEAN	SIGNIFICANCE OF DIFFERENCE BETW. MEANS
PEDX = 0 = 1	236 32	8.93 15.69	0.59 1.99	< 0.001
ZEBRA = 0 = 1	239 29	9.10 14.97	0.60 2.02	0.002
PELICN = 0 = 1	265 3	9.59 22.67	0.58 8.67	0.019

E. Effect of potential roadside hazards

Sections with garages or public houses have higher accident totals but the difference is not significant (see Table 6.9).

Sections with 1 or 2 bus stops have slightly higher accident totals (but difference not significant). Those with three or more bus stops have extremely high accident totals (significant at better than 0.001 probability) but this does not necessarily indicate that multiple bus stops are hazards. It may simply be due to the fact that they are usually found in major shopping centres where accident rates are likely to be high as a result of other factors.

The inclusion of the parameters GARAGE, PUB and BUSSTP in the regression analysis would increase the r^2 value by only 0.014, to 0.396

TABLE 6.9

Effect of garages, public houses and bus stops on accident rate

COMPARISON	NO. OF SECTIONS	MEAN ACCIDENT TOTAL	STD. ERROR OF MEAN	SIGNIFICANCE OF DIFFERENCE BETW. MEANS
GARAGE = 0 = 1+	245 23	9.67 10.43	0.60 2.43	0.717
PUB = 0 = 1+	248 20	9.49 12.85	0.61 2.16	0.132
BUSSTP = 0 = 1-2	142 121	8.77 10.14	0.75 0.86	0.231
BUSSTP = 0 = 3+	142 5	8.77 27.40	0.75 6.10	< 0.001

F. Geometrical and traffic management features

(i) Road Width. There is a strong positive correlation between road width and accident total ($r = 0.403$, $p < 0.001$) i.e. accident totals are greater on wider roads. However, this may simply reflect the fact that, in general, wider carriageways are provided on the more heavily-trafficked routes and, because of the greater traffic volumes, accidents are more frequent on these roads.

Regressing road width against traffic volume gives the equation

$$\text{WIDTH} = 0.2135\,(\text{TRAFF}) + 6.144$$
$$(r^2 = 0.434)$$

This gives an indication of the average road width associated with a particular traffic volume. It may well be that a section of road which is unduly narrow in relation to the traffic volume may be hazardous. Accordingly, a new variable, WDEF, was computed. This is the width deficiency calculated on the basis of the above equation. The correlation coefficient for WDEF v. TOTACC is -0.142 ($p = 0.010$) which indicates that accident totals are actually reduced as width deficiency increases. Thus, although an inadequate road width may be an impediment to flow, it cannot be considered to constitute a hazard.

(ii) Curvature. The correlation coefficient between BEND and TOTACC indicates that there is a significant negative correlation between the two variables (r = -0.108, p = 0.039). The correlation with WETACC is also negative (but not quite significant, r = -0.100, p = 0.052) and with WETSKD is positive but not significant (r = 0.042, p = 0.427).

These results are somewhat surprising since it is to be expected that accident rates would be greater on bends because of reduced sight distances, greater lateral forces, etc. A possible explanation is that road users are themselves aware of the potential dangers and take greater care. Furthermore, highway authorities do endeavour to reduce the accident risk by eliminating other possible hazards on bends (bus stops, garages, accesses, etc.) where possible.

(iii) Gradient. There is a highly significant negative correlation between gradient (GRAD) and total accidents (r = -0.163, p = 0.004). The correlation coefficients for wet-road and wet-road skidding accidents are also negative but are not significant (GRAD v. WETACC, r = -0.610, P = 0.160 and GRAD v. WETSKD, r = -0.054, p = 0.191).

In LR510 (see Table 5.9) it is suggested that sites with gradients of 5% or steeper (longer than 100 metres) should be classed as 'difficult' and should attract an appropriately high risk rating. Table 6.10 shows that on average the 14 sites in this category actually have significantly lower accident totals than the remaining sites. Wet-road and wet-road skidding accident totals are not significantly above average. Thus, there would appear to be no justification for assigning a high risk rating to an urban site on account of its gradient, at least within the range 0 to 8% encountered in this study.

TABLE 6.10

Effect of road gradient on accident rate

GRADIENT (%)	NO. OF SITES	ACCIDENT PARAMETER	MEAN ACCIDENT RATE	STD. ERROR OF MEAN	SIGNIFICANCE OF DIFFERENCE BETW. MEANS
below 5 5+	254 14	TOTACC	9.95 5.86	0.61 1.51	0.022
below 5 5+	254 14	WETACC	2.61 2.71	0.18 0.87	0.893
below 5 5+	254 14	WETSKD	0.26 0.29	0.04 0.19	0.893

Inclusion of WIDTH, BEND and GRAD in the regression analysis, together with TRAFF, SHOPS, JCT and PEDX, would increase the r^2 value by only 0.016.

(iv) Bus lane. Twenty-eight of the sections had a bus lane. The total accident rate on these sections is higher than on the remainder but the difference is not significant.

TABLE 6.11

Effect of bus lanes and one-way flow on accident rate

COMPARISON	NO. OF SECTIONS	MEAN ACCIDENT RATE	STD. ERROR OF MEAN	SIGNIFICANCE OF DIFFERENCE BETW. MEANS
Bus Lane=0 =1+	240 28	9.45 12.18	0.63 1.39	0.155
One-way flow Two-way flow	13 255	3.31 10.07	0.67 0.61	< 0.001

(v) One-way flow. At the thirteen sections where there was one-way flow the accident rates are very much lower than elsewhere (see Table 6.11 above). Clearly, this is due mainly to the removal of conflicts arising from opposing traffic flows.

Introducing ONEWAY into the regression analysis as a dummy variable (one-way flow = 0, two-way = 1) gives

$$TOTACC = 1.390\ (SHOPS) + 0.324\ (TRAFF) + 1.257\ (JCT) + 5.042\ (ONEWAY) + 2.256\ (PEDX) - 6.924$$

$$(r^2 = 0.393)$$

MISSING

PRINT

Adding BUSL to the regression would give an increase of only 0.002 in r^2.

G. Regression with all principal site parameters (excluding SFC).

When all the major objective site parameters except SFC are included in the regression analysis the equation shown in the analysis summary below is obtained.

DEPENDENT VARIABLE..... TOTACC NO OF CASES.. 268

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B (COEFFICIENT)
SHOPS	0.49368	0.24372	0.24372	0.49368	1.212768
TRAFF	0.59329	0.35199	0.10827	0.44929	0.242489
TJCT	0.60711	0.36858	0.01659	0.25462	1.434697
WIDTH	0.61965	0.38397	0.01538	0.40320	0.463897
ONEWAY	0.62787	0.39422	0.01025	0.15170	3.920430
XRD	0.63491	0.40312	0.00889	0.07996	2.901948
BUSSTP	0.64233	0.41259	0.00947	0.19068	0.948519
PEDX	0.64609	0.41743	0.00485	0.22885	2.575797
MINACC	0.64766	0.41947	0.00204	-0.27737	-0.386345
MAJACC	0.64928	0.42156	0.00210	0.07015	0.847254
HOUSNG	0.65092	0.42370	0.00214	-0.32143	0.013527
BEND	0.65242	0.42565	0.00195	-0.10787	-0.049154
PUB	0.65369	0.42731	0.00166	0.06753	-1.296944
BUSL	0.65456	0.42845	0.00114	0.09056	0.862931
COMM	0.65492	0.42893	0.00048	0.04780	-0.220218
OPENSP	0.65527	0.42937	0.00045	-0.09847	-0.152015
GRAD	0.65550	0.42968	0.00031	-0.16331	0.118904
(CONSTANT)					-8.482586

(GARAGE REJECTED FROM REGRESSION)

The corresponding regression analysis summaries for wet-road accidents and wet-road skidding accidents are shown in Table 3 of Appendix D. The parameters are ranked in order of their ability to account for variance in the dependent variable when in combination with the other parameters (the simple correlation coefficient, r, shown for each parameter is a measure of its ability to explain the variation when it is the only predictor variable). It will be seen that only the first three or four parameters in the list contribute substantially to explaining the variance in accident total; the remainder give only a minimal improvement.

The overall r^2 values are

TOTACC	0.430
WETACC	0.213
WETSKD	0.093

The equivalent r^2 values obtained with the subjective risk rating RRY (for the same 268 sections) are 0.197, 0.076, 0.001. Thus the regression equation using 18 objective site parameters is demonstrably superior to the subjectively-assessed risk rating as a predictor of relative accident risk. Forty-three percent of the variation in overall accident numbers is explained by the variables in the regression equation compared with only 20% explained by the subjective risk rating.

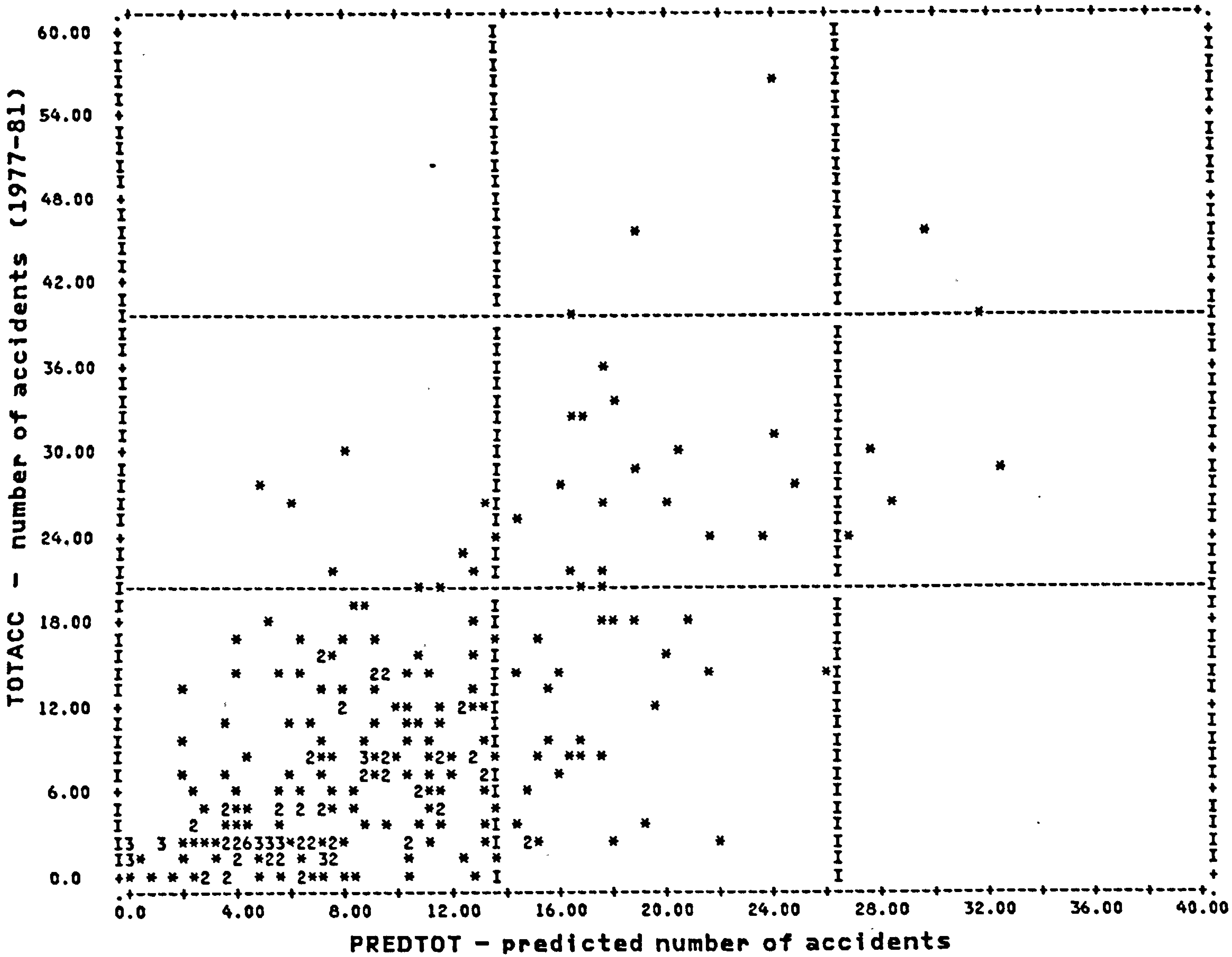
Figure 6.4 is a scattergram of accident total predicted from the regression equation (PREDTOT) against actual accident total for each of the 268 sections. When this is compared with the equivalent scattergram for Risk Rating (RRY) against accident total (Figure 6.2) the superiority of the objective assessment is immediately apparent.

H. Effect of skid resistance.

Before examining the influence of skid resistance it is necessary to exclude sections with high SFC variation (standard deviation 0.06 or greater). The remaining 238 sections produced the following correlation coefficients (all negative) between SFC and accidents :-

TOTACC	-0.114	(p = 0.039)
WETACC	-0.201	(p = 0.001)
WETSKD	-0.085	(p = 0.095)
ACCRAT	-0.075	(p = 0.125)
WETRAT	-0.167	(p = 0.005)
SKRAT	-0.059	(p = 0.183)
PCWET	-0.089	(p = 0.085)
PCSKID	-0.019	(p = 0.383)
XSWET	-0.182	(p = 0.002)

The correlation with total accidents is significant (at probability 0.039) and with wet-road accidents is highly significant (p = 0.001). Only a weak correlation is found with number of wet-road skidding accidents and with percentage skidding. This does not necessarily mean that there is no association between skid resistance and skidding accident rate; perhaps it simply serves to illustrate that the low incidence and/or unreliable reporting of skids in London make it difficult to establish the link between the two parameters. The



correlation (r) = 0.65835

r squared = 0.43343

significance < 0.00001

intercept = -0.23799

slope = 1.02229

no. of values = 268

FIG. 6.4 Predicted accident total v. actual accident total percentage wet might have been expected to correlate well with SFC but that is not the case. On the other hand, XSWET does correlate well ($r = -0.182$, $p = 0.002$) and may prove to be a more useful parameter for identifying sites with inadequate skid resistance.

Regressing SFC and TRAFF with TOTACC, WETACC, WETSKD and XSWET gives

$$TOTACC = 0.450\ (TRAFF) - 0.119\ (SFC) + 2.640 \qquad (r^2 = 0.210)$$
$$WETACC = 0.102\ (TRAFF) - 0.103\ (SFC) + 3.862 \qquad (r^2 = 0.129)$$
$$WETSKD = 0.012\ (TRAFF) - 0.008\ (SFC) + 0.280 \qquad (r^2 = 0.038)$$
$$XSWET = 4.268 - 0.098\ (TRAFF) - 0.014\ (SFC) \qquad (r^2 = 0.035)$$

Reducing the number of sections from 268 to 238 in the overall regression (TOTACC with all variables except SFC) reduces the r^2 value from 0.43 to 0.37. This is because a high proportion of the sites which are excluded on account of high variability in SFC are at locations where anti-skid surfacing has been laid (prior to 1976) in part of the section. They are mostly areas with many hazard features at which the accident rate, although probably lower than the rate prior to treatment, is above average.

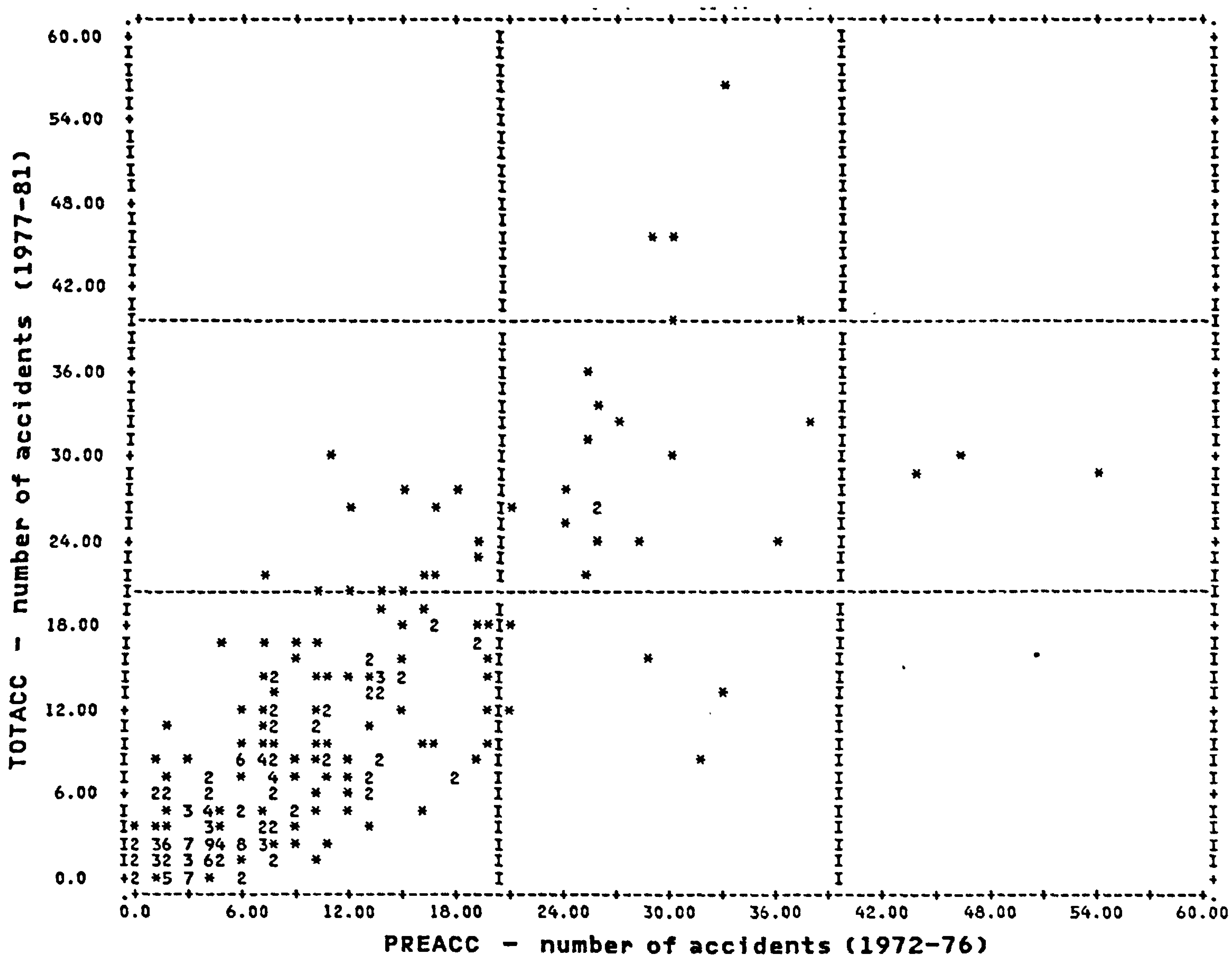
The summaries of the regression analyses with SFC added to the other 18 predictor variables are shown in Table 3 of Appendix D. Adding SFC to the regression for TOTACC increases the r^2 value by only 0.001. (from 0.372 to 0.373). Thus SFC is of no great value in predicting total accidents. It will be seen from the regression summaries that SFC is only the 10th most important predictor of total accidents. For WETACC it rises to 3rd place but drops to 8th for WETSKD. For XSWET it is the most important predictor but the r^2 value for the XSWET regression is only 0.103.

The correlation between the various accident parameters and simple transformations of SFC (SFC^2, $\sqrt{SFC}$, $1/SFC$, etc.) was investigated (see Table 2 in Appendix D) and several of them were found to give higher correlation coefficients than SFC. The strongest correlations were found with $1/SFC^2$. This suggests that the relationship between SFC and accidents is not linear and this will be investigated in Chapter 7. The use of the parameter $1/SFC^2$ in place of SFC in the multiple regression equations produced virtually no improvement in the r^2 value.

6.3 ACCIDENT HISTORY.

In relation to the number of road-user conflicts at a particular location, accidents are extremely rare events and there is a large random element in their occurrence. Nevertheless in assessing need and priority for treatment it is usually necessary to examine data on past accidents and to assume that the future accident pattern will be similar providing the site conditions remain the same. In order to test the validity of this assumption accident totals for the 268 study sections were extracted from ACCSTATS for the five years (1972-6) prior to the study period. Figure 6.5 shows the previous accident total (PREACC) plotted against accident total (TOTACC) for each site. It will be seen that there is far less scatter than in Fig. 6.4 (total accidents v. number predicted from multiple regression equation). This confirms that examination of data for past accidents is by far the best means of assessing current (or future) accident risk.

The r^2 value for TOTACC v. PREACC is 0.65, compared with 0.43 for TOTACC v. PREDTOT and 0.20 for TOTACC v. RRY.



correlation (r) = 0.80472
r squared = 0.64757
significance < 0.0001
intercept = 0.97757
slope = 0.87384
no. of values = 268

FIG. 6.5 Accident total (1977-81) v. total in previous five years

6.5 CONCLUSIONS

1. Of the alternatives considered, examination of past accident data is by far the best method of assessing future accident risk at an existing site.

2. Subjective risk rating can be reasonably good when only a small number of sites of similar character are to be compared but is unsatisfactory when large numbers of dissimilar sites are involved.

3. If past accident records are not available (or are no longer relevant) a better alternative is the use of objectively-assessed site parameters as predictor variables in a linear regression equation.

4. For predicting relative accident totals on main roads in London the most important parameters are traffic flow, proportion of frontage occupied by shops, and presence of junctions. Site geometry (curvature, gradient, etc.) is of little significance.

5. Measured skid resistance is a poor predictor of skidding accident risk.

6. The correlation between SFC and wet-road accident rate is highly significant but SFC alone is not as good a predictor of wet-road accident risk as a regression equation based on site parameters other than SFC.

CHAPTER 7

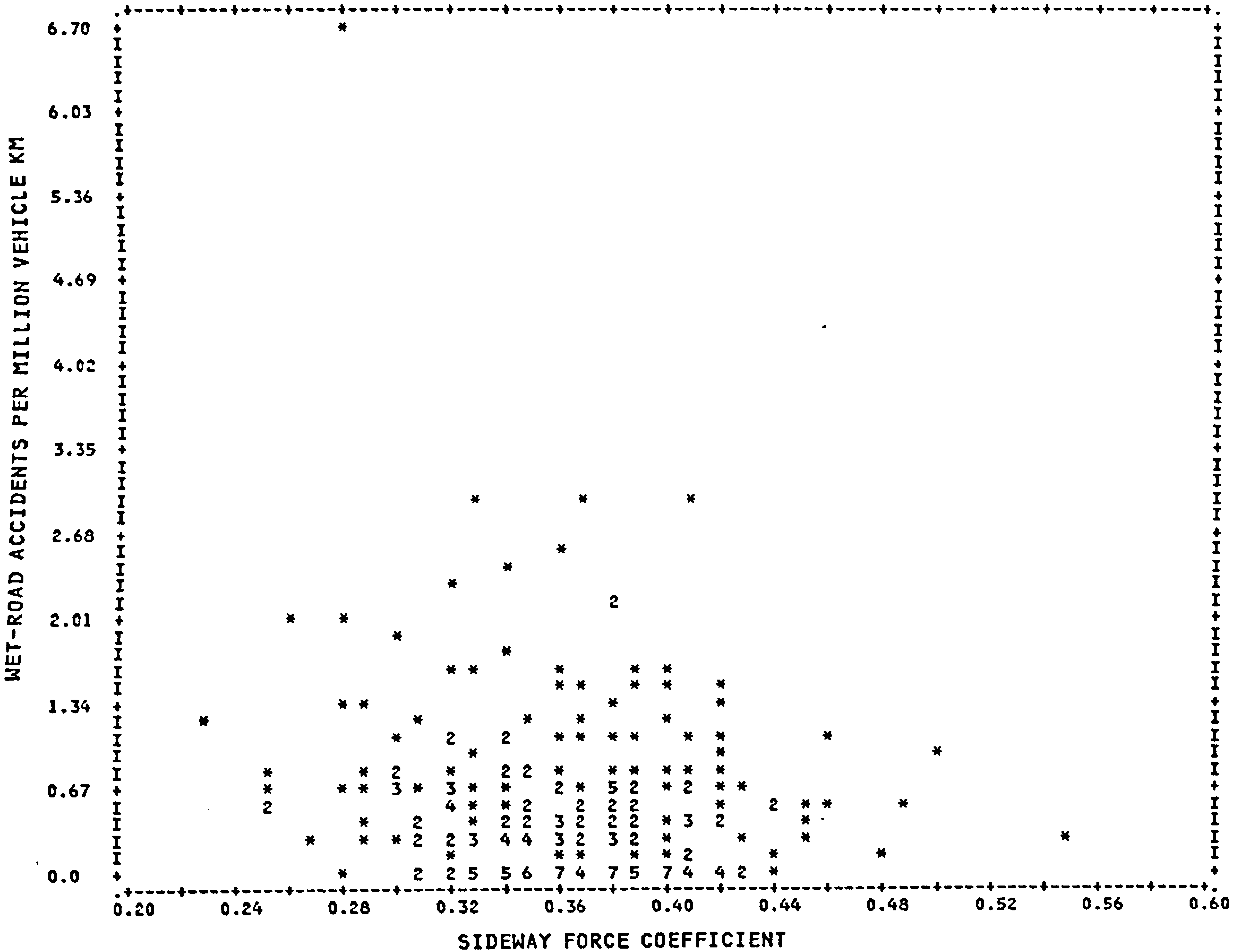
THE EFFECT ON ACCIDENT RATE OF A CHANGE IN SKID RESISTANCE.

7.1 THE RELATIONSHIP BETWEEN ACCIDENT RATE AND SKID RESISTANCE.

7.1.1 Introduction.

In Chapter 6 it was established that the skid resistance of the road surface is a relatively minor determinant of the overall accident rate at an urban location. Other factors such as nature of roadside land use and presence of junctions have a greater effect because they directly influence the generation of road-user conflicts which can result in collisions. One reason why skid resistance is a secondary factor is that at most urban locations it becomes important only after an emergency situation has arisen requiring a driver to swerve or brake sharply to avoid a collision. In the context of accident remedial measures it assumes greater importance because it is one of the few factors which can be changed easily and relatively cheaply. After an improvement in skid resistance the primary accident causation factors will remain unchanged and emergency braking or swerving situations will occur with the same frequency but the consequences are likely to be less severe.

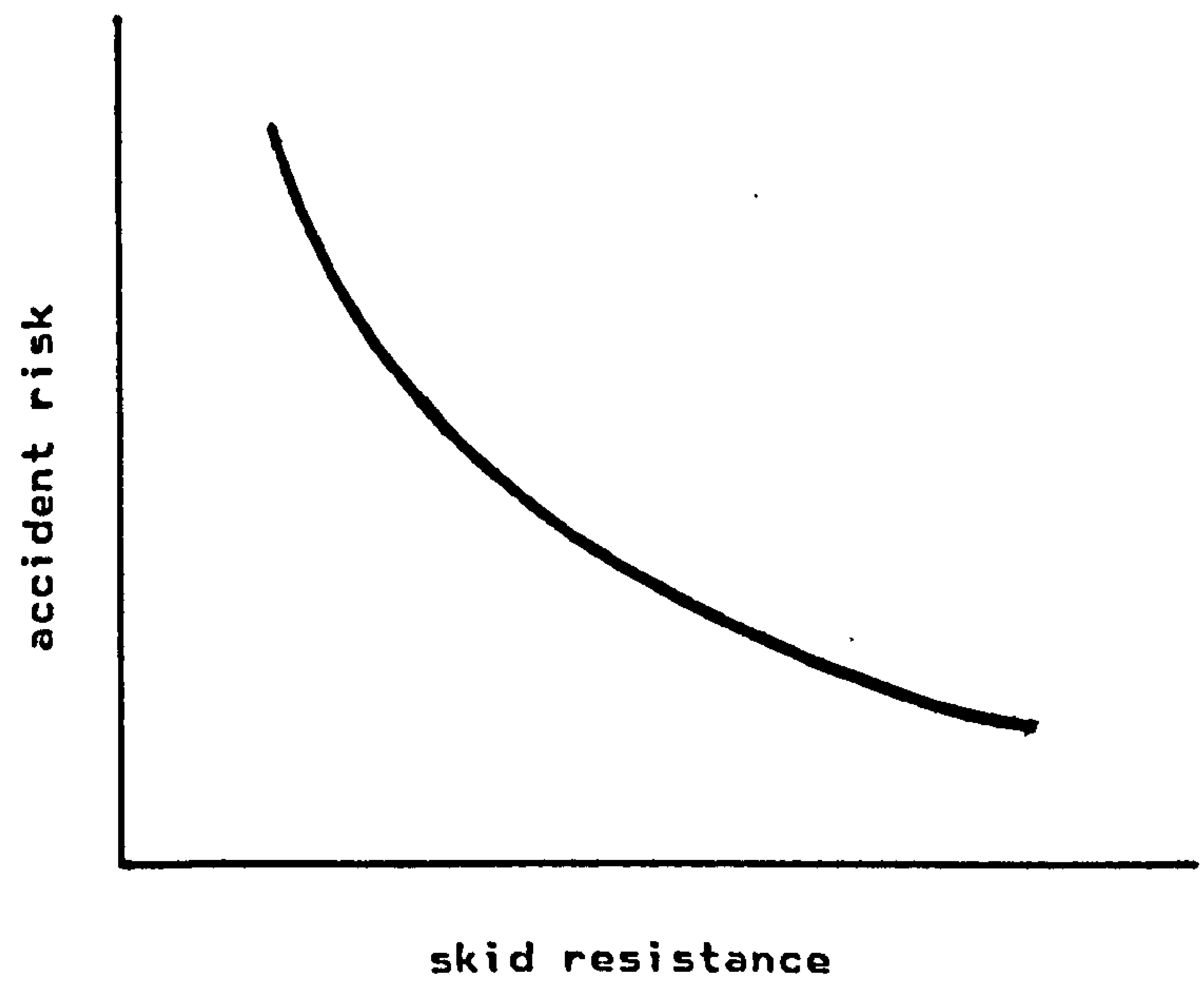
It has long been known that improving the skid resistance of a road surface can reduce the risk of certain types of accident. A number of workers have attempted to establish the relationship between skid resistance and accident rate in order to define minimum acceptable levels of skid resistance or to predict the saving in accidents that could be achieved by improving skid resistance. No-one has yet been able to to this satisfactorily. One of the fundamental problems is that because of the subsidiary nature of skid resistance as a factor in accidents the relationship is not a precise one. This is especially true on urban roads, where the road-user interactions are generally much more complex than on rural roads. Figure 7.1 shows wet-road accident rate (accidents per million vehicle kilometres) plotted against SFC for the 238 sections of road in Borough B (described in Chapter 6). It will be seen that, although there is a statistically significant linear association between the two variables ($r = -0.167$, $p = 0.005$), there is a very wide scatter of individual points. Equivalent plots produced by Blackburn et al (98) and Rizenbergs et al (99) exhibit a similar degree of scatter. It should



correlation (r) = -0.16743
r squared = 0.02803
significance = 0.00483
intercept = 1.49515
slope = -2.50334
no. of values = 238

FIG. 7.1 Wet-road accidents per million vehicle km v. SFC (Borough B sections) be noted that, although a significant association between two variables may be demonstrated and a regression equation calculated and best-fit line (or curve) drawn through a group of points, the scatter about the best-fit line may be such that it is of limited predictive value. That is the case with the data shown in Fig. 7.1 (as well as with the previously-published data referred to above).

Conceptually, the likely relationship between skid resistance and accident risk may be represented by a curve of the form shown below, with accident risk increasing as skid resistance decreases (assuming otherwise homogeneous conditions).



The curve is likely to be smooth with no abrupt changes or 'critical' skid resistance levels. As the skid resistance approaches very low levels the accident risk must rise very sharply because drivers would then have little control over their vehicles. At very high levels of skid resistance the risk curve will tend to level out and a point will eventually be reached where an increase in skid resistance will not reduce accident risk any further.

Giles (12) stressed that there can be no simple dividing line between a satisfactory and an unsatisfactory skid resistance but his findings (discussed in Chapter 5) do suggest that it is almost inevitable that a site with SFC below 0.32 will become a skidding accident black spot. However, Fig.7.2 (a plot of number of wet-road

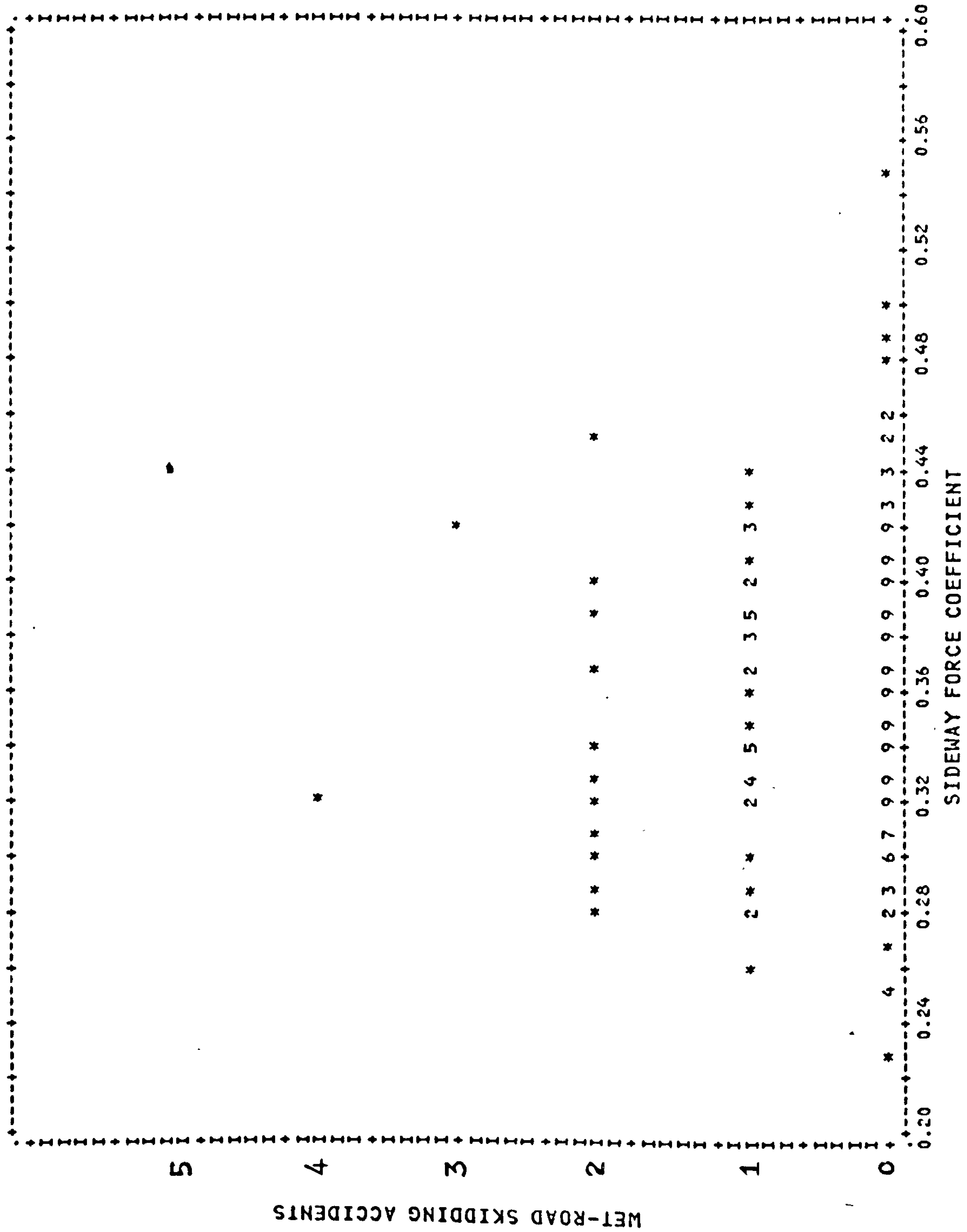


FIG. 7.2 <u>Number of wet-road skidding accidents v. SFC (Borough B sections)</u>

skidding accidents in the 100-metre Borough B sections against SFC) shows that this is not the case on urban roads; the SFC at 33 (of 238) of the Borough B sites was below 0.32 but at 24 of these sites there were no skidding accidents reported in the five-year study period. There were two skidding accidents at 4 of the sites and just one at each of the remaining 5 sites. The mean number of accidents of all types was higher at the low-SFC sites (12.9 compared with 8.3 at the remaining sites - difference significant at 0.005 probability level) but at more than half of the low-SFC sites the accident total was below the average. This indicates that in urban areas there are many sections of road where low skid resistance does not constitute a hazard (for example at locations where vehicle speeds are very low and hence the level of frictional demand is low).

Rizenbergs (99) investigated wet-road accident risk in relation to skid resistance on rural roads in Kentucky and claims to have identified a Skid Number (measured at 40 mile/h) of 40 (equivalent to an SFC of about 0.50) as a critical value below which the risk increased very rapidly and above which it levelled out. Most investigators have found that within the skid resistance range encountered on normal roads (roughly SFC 0.20 to 0.65) there is no evidence of any abrupt transitional level. The results of studies reported by Schlosser (100), Schulze (101), Ivey (97) and Blackburn et al (98) suggest that at the higher end of the skid resistance range, although there may be some fall-off in the rate at which accident risk decreases with increasing SFC, there is no evidence that the accident risk reaches an asymptotic level. The implication of this is that in terms of improving skid resistance there is no limiting SFC (within the achievable range) beyond which no further accident savings can be achieved.

7.1.2 Further analysis of Borough B data.

7.1.2.1 Linear regressions

Several workers (97,98) investigating the relationship between skid resistance and accident rate have found that in general, within the skid resistance ranges they encountered, a straight line fitted their data no less well than any curve. If there is little difference in goodness-of-fit then it is generally desirable to opt for the linear rather than the curvilinear model, because it is simpler to use.

In multiple linear regression analyses in the present study a linear model of the form

$$A = B_1V_1 + B_2V_2 + B_3V_3 + \ldots\ldots\ldots\ldots + C$$

is assumed where A is the dependent accident variable, V_1, V_2, etc. are the independent predictor variables, B_1, B_2, etc. are multiple regression coefficients (partial slopes) and C is a constant.

A simple linear regression of TOTACC (five-year accident total) on SFC for the 238 hundred-metre sections of road in Borough B produced the following equation :

$$\text{TOTACC} = 16.669 - 20.834\ (\text{SFC})$$
$$r = -0.114$$
$$r^2 = 0.013$$
$$\text{standard error (s.e.)} = 0.118$$

The r value of -0.114 indicates that SFC correlates significantly (probability, $p = 0.039$) with TOTACC. The r^2 value of 0.013 indicates that SFC explains 1.3% of the variation in accident total. Account must, however, be taken of the fact that the level of traffic flow has a strong direct influence on accident rate (r for TRAFF v. TOTACC = 0.449, $p < 0.001$) and also an indirect influence since SFC decreases as traffic flow increases (r for TRAFF v. SFC = 0.110, $p=0.045$). Thus, there is a complex interaction between number of accidents, traffic flow and SFC.

Regressing TOTACC on TRAFF gave the equation

$$\text{TOTACC} = 0.457\ (\text{TRAFF}) - 1.860$$
$$r^2 = 0.205$$
$$\text{s.e.} = 0.059$$

Thus, TRAFF explains 20.5% of the variation in TOTACC.

Regressing TOTACC on TRAFF and SFC together gave the equation

$$TOTACC = 0.450\,(TRAFF) - 11.90(SFC) + 2.640 \qquad \underline{\text{Eq. R1}}$$

$r^2 = 0.209$

s.e. (overall) = 7.810

s.e. (TRAFF) = 0.059 *

s.e. (SFC) = 10.645; not significant (NS)

Thus, the inclusion of SFC in the regression has increased the proportion of explained variance in accident total by only 0.4% (It was shown in Chapter 6 that the inclusion of other predictor variables could increase the proportion of explained variance to 37% but the standard error of the SFC term is then higher).

The 95% confidence limits for each regression coefficient are $\pm$ 1.96(s.e.). Hence a coefficient is significantly different from zero if the ratio of the coefficient to its standard error is greater than 1.96. Significance is shown by an asterisk beside the standard error value.

The above regression equation could be used to predict the accident total at any site from a knowledge of the traffic flow and skid resistance but in the present context it is of more interest to predict the effect on accident rate of an increase in skid resistance, with traffic flow remaining constant. The regression coefficient of -11.9 for SFC indicates a reduction of 1.19 accidents (in five years) for an increase of 0.10 in SFC. Since the mean accident total is 9.09 this is equivalent to a reduction of 13.1% in total accidents per 0.10 increase in SFC. However, the value of 10.6 for the standard error of the SFC regression coefficient indicates that the confidence limits about the prediction are very wide. The 95% confidence limits for the predicted mean change in accident total are $\pm$ 2.08 (1.96 x s.e. x 0.10), i.e. ranging from a reduction of 3.27 to an increase of 0.89. Clearly this estimate is of little value since the confidence limits include zero and negative values.

Regressing WETACC (number of wet-road accidents) on traffic flow and SFC gave

$$WETACC = 0.102\ (TRAFF) - 10.30\ (SFC) + 3.862 \qquad \underline{R2}$$

$r^2 = 0.129$

s.e. (overall) = 2.794

s.e. (TRAFF) = 0.021 *

s.e. (SFC) = 3.759 *

The partial slope for SFC of -10.3 (with a standard error of 3.8) indicates that for an increase of 0.10 in SFC the predicted mean change in wet-road total is a reduction of 1.03 ± 0.74. If it is assumed that the increase in skid resistance affects only wet-road accidents then this is equivalent to a predicted mean reduction of between 3.2% and 19.5% in the overall accident rate at the Borough B sites. The precision of this estimate is considerably better than the earlier one, due perhaps to the fact that SFC has a more direct bearing on wet-road accidents than on accidents generally, but the confidence limits are still extremely wide.

It must be emphasised that the confidence limits calculated for these regressions should be used with caution because, as is frequently the case in such applications, several of the underlying assumptions of regression analysis are not justified for some of the parameters examined. In particular, the distribution of accident totals is highly skewed and there is an interaction between the two 'independent' variables, SFC and traffic flow. This will reduce the accuracy of the stated confidence intervals (and significance levels) but it is, nevertheless, reasonable to assume that the confidence intervals can be used on a comparative basis.

Regressing ACCRAT (accidents per million vehicle km) and WETRAT (wet-road accidents per million vehicle km) on SFC gave

$$ACCRAT = 3.047 - 2.812\ (SFC) \qquad \underline{R4}$$

$r^2 = 0.006$

s.e. (overall) = 1.798

s.e. (SFC) = 2.438 NS

$$WETRAT = 1.495 - 2.503\ (SFC) \qquad \underline{R5}$$

$r^2 = 0.028$

s.e. (overall) = 0.708

s.e. (SFC) = 0.960 *

Clearly, SFC is a very poor predictor of total accident rate. it explains only 0.6% of the variation in ACCRAT. It is somewhat better as a predictor of wet-road accident rate but still explains only 3% of the variation in WETRAT.

It was noted in Chapter 5 that at all the wet-road skidding accident black spots in London the proportion of accidents on wet road surfaces was high and that 'percentage wet' might, therefore, be a useful parameter for identifying sites with inadequate skid resistance. It has considerable appeal as a parameter for this purpose because it is dimensionless and likely to interact more strongly than other accident parameters with SFC.

The correlation coefficient (r) for SFC v. Percentage Wet (PCWET) was 0.089, which is not quite significant ($p = 0.085$). The r value for TRAFF v. PCWET was almost zero (0.011), indicating virtually no association between traffic flow and percentage wet for the Borough B sites.

The regression analysis of percentage wet on traffic flow and SFC gave the equation

$$PCWET = 47.120 - 51.561\ (SFC) \qquad \underline{R3}$$

$r^2 = 0.008$

s.e. (overall) = 27.605

s.e. (SFC) = 37.417 NS

(note: TRAFF rejected from regression equation because its contribution to explaining variance in PCWET is negligible.)

The coefficient of the SFC term indicates a fall of 5.2 in percentage wet per 0.10 increase in SFC but the 95% confidence limits are very wide (-2.2 to + 7.3) and, since they include zero, it must be accepted that the slope of the SFC term has not been shown to be significantly different from zero. This is a disappointing conclusion. It may well result from the use of fairly short study sections (100 metres), in some of which the number of accidents is very low. Small differences in accident numbers can then have a disproportionately large effect on a percentage parameter such as PCWET. The use of a longer section length would give larger numbers of accidents and this would reduce the random variability in PCWET and possibly produce a statistically significant conclusion. For this reason it was decided to study an additional group of sites which would consist of whole links rather than 100-metre sections within a link. The link study is described in section 7.1.3.

7.1.2.2 Non-linear regressions

As noted in Chapter 6, several simple functions of SFC correlated marginally more closely with some of the accident parameters than did SFC, with the function ($1/SFC^2$) generally giving the highest correlation coefficient. Inserting this function into the basic linear model gives a non-linear expression relating SFC, traffic and accidents, of the form.

$$A = C + B_1(TRAFF) + B_2/(SFC)^2$$

This equation is interesting because it produces a curve similar to the conceptual accident risk/SFC curve discussed in Section 7.1.

Separate regression analyses for total accidents (TOTACC), wet-road accidents (WETACC) and percentage wet (PCWET) on traffic flow (TRAFF) and the reciprocal of $(SFC)^2$ produced the following equations.

$$TOTACC = 0.442\ (TRAFF) + 0.312/(SFC)^2 - 4.000 \qquad \underline{R6}$$

$r^2 = 0.212$

s.e. (overall) = 7.794

s.e. (TRAFF) = 0.059 *

s.e. ($1/SFC^2$) = 0.222 NS

WETACC = 0.096 (TRAFF) + 0.250/(SFC)^2 - 1.749 R7

r^2 = 0.139

s.e. (overall) = 2.741

s.e. (TRAFF) = 0.021 *

s.e. (1/SFC^2) = 0.078 *

PCWET = 1.162/(SFC)^2 + 19.09 R8

r^2 = 0.0095

s.e. (overall) = 27.585

s.e. (1/SFC^2) = 0.774 NS

(TRAFF rejected as having negligible effect)

Regressing accidents per million vehicle kilometres (ACCRAT) and wet-road accidents/ mvkm (WETRAT) on (1/SFC^2) gave the following equations

ACCRAT = 1.394 + 0.0790/(SFC)^2 R9

r^2 = 0.010

s.e. (overall) = 1.794 NS

s.e. (1/SFC^2) = 0.050 NS

WETRAT = 0.107 + 0.0598/(SFC)^2 R10

r^2 = 0.037

s.e. (overall) = 0.705

s.e. (1/SFC^2) = 0.020 *

In all five equations using (1/SFC^2) the overall standard error is lower than for the equivalent equations (R1 to R5) in which (SFC) was used. However, the improvement is only slight and the confidence limits about the regression coefficients are still too wide to justify practical use of any of these equations to predict potential accident savings.

7.1.3 Link study

7.1.3.1 Introduction

The regression analyses described above on data from the Borough B sections revealed that SFC had a significant effect on wet-road accident rate but the effect on overall accident rate and on percentage wet was not shown to be significant. A further study was carried out with the aim of establishing significant relationships between overall accident rate and SFC, and percentage wet and SFC, and improving the precision of predictions relating to wet-road rates. It was considered that this might best be achieved by using longer study section lengths (and hence greater numbers of accidents) and by ensuring that the roadside land use within each section was homogeneous (in order to reduce variability in accident rate due to variation in land use).

7.1.3.2 Site selection and data collection

The principal sources of data were

- GLC SCRIM survey results
- the GLC accident data bank (ACCSTATS)
- a listing provided by the GLC Traffic Survey Section of estimated daily traffic flows for most of the links in the classified road network
- a video film giving a driver's-eye view of the Principal road network.

A representative sample of thirteen boroughs (out of a total of 32) was selected for study. It was decided that the sections should be whole links (i.e. sections of road between major intersections) rather than fixed lengths of road because this would greatly simplify the extraction of accident data. The criteria for inclusion of a link were

- homogeneous roadside land use
- uniform skid resistance
- known traffic flow
- length at least 100 metres

Two-hundred and thirty-seven acceptable links were found. The coded raw data for each link are shown in Table 1 of Appendix E, where Table 2 gives a statistical summary of the input data and Table 3 the frequency distribution of SFC values.

A Land Use

The video film was used to examine each route and identify links where the roadside land use was uniform (or substantially so) and in one of the following three categories :-

- RESIDENTIAL (coded 1)
- SHOPPING (coded 2)
- OPEN (coded 3)

B Skid Resistance

The 1979 SCRIM survey results were used; each reading having been adjusted to give an estimated mean summer SFC value. Links were excluded where the standard deviation was 0.06 or greater. Links were also excluded where it was known that resurfacing or surface treatment had taken place during the proposed accident study period (1978-80) or the preceding two years. Mean SFC values ranged from 0.29 to 0.58 (see Appendix E).

C Traffic Flow

Traffic flow (TRAFF) in thousands of vehicles daily was noted, together with the length of the link in tens of metres.

D Accident Data

Accident information for the three-year period 1978-80 was obtained from standard ACCSTATS listings giving a single-line summary of the individual accidents in each link of the classified road network. For each of the selected links the following information was extracted :-

- total number of accidents (TOTACC)
- number of wet-road accidents (WETACC)
- number of wet-road skidding accidents (WETSKD)

and subsequently the accident parameters listed below were computed.

- percentage on wet road surface (PCWET)
- accidents per km (TOTDENS)
- wet-road accidents per km (WETDENS)
- wet-road skidding accidents per km (SKIDDENS)
- accidents per million vehicle km (ACCRAT)
- wet-road accidents per million vehicle km (WETRAT)
- wet-road skidding accidents per million vehicle km (SKRAT)

7.1.3.3 Data analysis

The correlation coefficients shown below indicate a substantially closer association between SFC and accidents for the links compared with the Borough B sections.

	LINKS	BOROUGH B
TOTDENS/TOTACC	- 0.319*	- 0.144*
WETDENS/WETACC	- 0.353*	- 0.201*
SKIDDENS/WETSKD	- 0.134*	- 0.085
ACCRAT	- 0.240*	- 0.075
WETRAT	- 0.315*	- 0.167*
SKRAT	- 0.125*	- 0.059
PCWET	- 0.189*	- 0.089

* = significant at better than probability 0.05

Linear regressions of TOTDENS, WETDENS and PCWET on SFC and TRAFF, and of ACCRAT and WETRAT on SFC gave the following equations :

TOTDENS = 1.372 (TRAFF) - 80.41 (SFC) + 29.69 <u>R11</u>

r^2 = 0.349

s.e. (overall) = 19.55

s.e. (TRAFF) = 0.145 *

s.e. (SFC) = 26.11 *

WETDENS = 0.428 (TRAFF) - 41.34 (SFC) + 14.93 <u>R12</u>

r^2 = 0.292

s.e. (overall) = 7.74

s.e. (TRAFF) = 0.058 *

s.e. (SFC) = 10.34 *

PCWET = 0.335 (TRAFF) - 64.54 (SFC) + 43.88 <u>R13</u>

r^2 = 0.053

s.e. (overall) = 21.53

s.e. (TRAFF) = 0.160 *

s.e. (SFC) = 28.74 *

ACCRAT = 2.667 - 3.834 (SFC) <u>R14</u>

r^2 = 0.058

s.e. (overall) = 0.790

s.e. (SFC) = 1.010 *

WETRAT = 1.041 - 1.831 (SFC) <u>R15</u>

r^2 = 0.099

s.e. (overall) = 0.282

s.e. (SFC) = 0.360 *

It will be seen that, compared with the Borough B results, there is a substantial improvement in the proportion of explained variance in the accident parameters and the regression coefficients in all five equations are significantly different from zero.

Replacing SFC with $1/SFC^2$ in the regression analyses gave the equations

$$TOTDENS = 1.393(TRAFF) + 2.350/(SFC^2) - 18.432 \qquad \underline{R16}$$

$r^2 = 0.345$

s.e. (overall) = 19.622

s.e. (TRAFF) = 0.145 *

s.e. ($1/SFC^2$) = 0.845 *

$$WETDENS = 0.433\ (TRAFF) + 1.333/(SFC^2) - 10.438 \qquad \underline{R17}$$

$r^2 = 0.291$

s.e. (overall) = 7.745

s.e. (TRAFF) = 0.057 *

s.e. ($1/SFC^2$) = 0.334 *

$$PCWET = 0.346\ (TRAFF) + 2.013/(SFC^2) + 4.617 \qquad \underline{R18}$$

$r^2 = 0.052$

s.e. (overall) = 21.542

s.e. (TRAFF) = 0.159 *

s.e. ($1/SFC^2$) = 0.928 *

$$ACCRAT = 0.391 + 0.113/(SFC^2) \qquad \underline{R19}$$

$r^2 = 0.047$

s.e. (overall) = 0.794

s.e. ($1/SFC^2$) = 0.033 *

$$WETRAT = 0.0581/(SFC^2) - 0.0723 \qquad \underline{R20}$$

$r^2 = 0.095$

s.e. (overall) = 0.282

s.e. ($1/SFC^2$) = 0.0117 *

The use of ($1/SFC^2$) rather than SFC has made virtually no difference to the proportion of explained variance. The fact that the linear and curvilinear relationships appear to be of equal predictive value is, perhaps, a reflection of the weakness of the relationship between SFC and accident rate.

A linear relationship implies that the change in value of the accident parameter per unit increase in SFC is the same throughout the SFC range. For the limited range of SFC values on which the regression is based (0.29 to 0.58, with less than 3% of the values above 0.50) this may be realistic but it becomes less so at very high SFC levels. Since neither the accident rate nor the Percentage Wet can be less than zero there must ultimately be a reduction in the rate of change with increasing SFC. A curvilinear relationship is, therefore, likely to be of more use when it is necessary to make predictions involving SFC levels beyond the range of SFC values from which the regression equations were derived.

A second-order polynomial model of the form

$$A = B_1(TRAFF) + B_2(SFC) + B_3(SFC)^2 + C$$

was also investigated and the regression equations are given below. Separate standard error values are not shown for the SFC and SFC^2 terms when both variables appear in the same equation. In this situation the interpretation of the values is difficult but, as will be seen, the <u>overall</u> standard errors are generally slightly greater than those found in the equivalent equations already discussed. There is, therefore, unlikely to be any advantage in using this more complex model.

$$TOTDENS = 1.372(TRAFF) - 95.974(SFC)^2 + 13.100 \qquad \underline{R21}$$

$r^2 = 0.350$

s.e. (overall) = 19.901

s.e. (TRAFF) = 0.145 *

s.e. (SFC^2) = 31.023 *

(SFC rejected)

$$WETDENS = 0.429(TRAFF) - 128.67(SFC) + 104.21(SFC)^2 + 32.952 \qquad \underline{R22}$$

$r^2 = 0.293$

s.e. (overall) = 7.752

s.e. (TRAFF) = 0.058 *

PCWET = $0.335(TRAFF) + 68.30(SFC) - 158.51(SFC)^2 + 16.469$ <u>R23</u>

$r^2 = 0.054$

s.e. (overall) = 21.565

s.e. (TRAFF) = 0.160 *

ACCRAT = $2.761(SFC) - 7.869(SFC)^2 + 1.306$ <u>R24</u>

$r^2 = 0.059$

s.e. (overall) = 0.791

WETRAT = $1.781(SFC)^2 - 3.323(SFC) + 1.349$ <u>R25</u>

$r^2 = 0.099$

s.e. (overall) = 0.282

In all of the regression models examined so far the effects of the individual predictor variables have been additive. This involves the assumption that the change in the dependent variable (i.e. the accident parameter) arising from a change in SFC is not proportional to its original value. A model which is appropriate when the effects are believed to be proportional rather than additive is

$$A = (TRAFF)^p \times (SFC)^q \times C$$

Expressing this in logarithmic form gives

$$\log(A) = p \times \log(TRAFF) + q \times \log(SFC) + \log(C)$$

which can be treated as a linear equation with predictor variables log(TRAFF) and log(SFC). In the following expressions the logarithm (to base 10) of each of the standard variables is denoted by

LSFC
LTRAFF
LTOTDENS
LWETDENS
LPCWET
LACCRAT
LWETRAT

Regression analyses using these variables produced the following equations:

LTOTDENS = 1.1242 (LTRAFF) - 1.4426 (LSFC) - 0.8035

r^2 = 0.223

s.e. (overall) = 0.4308

s.e. (LTRAFF) = 0.1660 *

s.e. (LSFC²) = 0.5411 *

hence, $\text{TOTDENS} = 0.1572\ (\text{TRAFF})^{1.1242}\ (\text{SFC})^{-1.4426}$ R26

LWETDENS = 0.9806 (LTRAFF) - 1.7495 (LSFC) - 1.3314

r^2 = 0.211

s.e. (overall) = 0.4212

s.e. (LTRAFF) = 0.1623 *

s.e. (LSFC) = 0.5289 *

hence, $\text{WETDENS} = 0.0466\ (\text{TRAFF})^{0.9806}\ (\text{SFC})^{-1.7495}$ R27

LPCWET = 0.8334(LTRAFF) - 0.7991(LSFC) - 0.3097

r^2 = 0.061

s.e. (overall) = 0.6420

s.e. (LTRAFF) = 0.2474 *

s.e. (LSFC) = 0.8062 NS

hence, $\text{PCWET} = 0.4901\ (\text{TRAFF})^{0.8334}\ (\text{SFC})^{-0.7991}$ R28

LACCRAT = -1.1157(LSFC) - 0.4659

r^2 = 0.039

s.e. (overall) = 0.2995

s.e. (LSFC) = 0.3627 *

hence, $\text{ACCRAT} = 0.3421\ (\text{SFC})^{-1.1157}$ R29

LWETRAT = -1.3077 (LSFC) - 0.9083

r^2 = 0.038

s.e. (overall) = 0.3533

s.e. (LSFC) = 0.4279 *

hence, $\text{WETRAT} = 0.1235\ (\text{SFC})^{-1.3077}$ R30

With the exception of the regression for PCWET the overall r^2 values are lower than for the corresponding additive regressions. However, it may well be that this form of relationship has greater functional validity and this will be investigated in the following section.

7.2 OBSERVED EFFECT OF AN INCREASE IN SKID RESISTANCE.

7.2.1 Introduction.

Although skid resistance is a relatively minor determinant of overall accident rate, its influence has been shown to be significant and the regression equations developed in the previous section could be used for predicting the reduction in accidents which would result from an increase in SFC.

One of the limitations of any investigation based on regression analysis of SFC and accident rates at a number of locations is that an accident/SFC relationship so defined is associative but not necessarily functional, i.e. it may be used to predict the existing accident rate at an individual site in the study group on the basis of the known SFC but will not necessarily be reliable for predicting the change in accident rate which would result from a change in SFC. In order to determine which, if any, of the regression equations provide a reliable basis for estimating potential accident savings it is necessary to actually change the SFC at a number of sites and compare the predicted and observed effect on accident rates. The GLC anti-skid surfacing programme provided a means of doing this and also made it possible to determine directly the accident savings that could be achieved by increasing skid resistance to the highest practicably attainable level.

The GLC programme started in 1968 following the success of a small number of experimental sites which had been treated in the previous year. The programme developed rapidly and by 1973 about 500 sites had been treated, including a high proportion of the major accident black spots where a substantial number of wet-road skidding accidents had been reported. The present study (for reasons discussed below) relates to sites treated from 1973 onwards. Up to this time most of the sites had been selected for treatment because they had a substantial number of accidents of which a high proportion had occurred on wet roads. Sites were also treated where the accident records revealed a high incidence of wet-road skidding. From 1973 the results of the SCRIM surveys of the GLC road network became available and an additional criterion - relatively low skid resistance - was introduced. This led to a dual approach in selecting candidate treatment sites. The treatment of high wet-road accident rate sites continued, with priority being given to sites which also satisfied the further criterion of low SFC. Additionally, sites with very low skid resistance were treated if there were sufficient accidents to warrant such action. As the programme developed and the obvious skidding accident black spots had been dealt with the engineers responsible for site selection felt able to allocate some of their funds to the treatment of sites at which, although the accident rate was low, they considered that the accident potential was high.

A consequence of the broadening of the basis for selection was that the sites studied herein are not skidding accident black spots but are representative of a wide range of accident rates and SFC levels. This enhances their value as an experimental group because any conclusions that may be drawn concerning the effect on accident rates of an increase in skid resistance are more likely to be valid for the rest of the Principal road network in London and not just for the high accident rate locations.

The objective of this part of the study was to examine the characteristics of the treated sites (hereafter referred to as the 'experimental' sites) and the before-and-after accident rates in order to :

- establish the overall saving in accidents
- assess the predictive value of the associative relationships developed earlier.

Some of the data will also be used in Chapter 8 where consideration is given to ways of identifying the characteristics of sites which respond best to treatment.

7.2.2 Data collection.

7.2.2.1 Information required

The basic information required for each site was:

- location
- date of treatment
- skid resistance before and after treatment
- accident rates before and after treatment

7.2.2.2 Data sources

The principal sources of data were:

- a list provided by the GLC Highway Maintenance Division giving the location of all sites treated with anti-skid surfacing (resin/bauxite surface dressing) from 1967 onwards, together with the date of treatment
- GLC SCRIM survey results
- a listing provided by the GLC Traffic Survey Section of estimated daily vehicle flows for most of the links in the classified road network
- a video film of the Principal road network
- large-scale (1:1250) Ordnance Survey maps
- a listing (GASMAN) of the GLC accident location network giving the location description and grid reference of each node
- a list provided by the Metropolitan Police giving the location description and grid reference of each pedestrian crossing in London
- the GLC accident data bank

7.2.2.3 Data recorded

For each site the precise information recorded was:

- YEAR OF TREATMENT
- SITE CATEGORY
- BOROUGH
- GRID REFERENCE
- SFC BEFORE TREATMENT
- SFC AFTER TREATMENT
- ROADSIDE LAND USE
- TRAFFIC FLOW
- ACCIDENT TOTALS BEFORE TREATMENT
- ACCIDENT TOTALS AFTER TREATMENT

A Year of treatment

Because of the considerable year-to-year fluctuation in accident totals at an individual site it is necessary to use accident data for a number of years in order to obtain a representative value for the accident rate. For this study a three-year period was considered to be appropriate. Accident records from 1970 onwards are held in the ACCSTATS data bank and so the earliest treatment year consistent with obtaining three years 'before' accident data was 1973. Similarly, 1980 was the latest treatment year for which three years 'after' data were available. Thus, only sites treated in the period 1973-80 were considered.

B Site category

The site category of each location was established by viewing the video film. Approximately 90% of the sites treated were approaches to pedestrian crossings or light-controlled intersections (ATS junctions). The remaining sites were on low-radius bends, flyover ramps, approaches to roundabouts, etc. and, since the numbers in any one category were considered to be insufficient to permit general conclusions to be drawn, they were not included in the study.

The pedestrian crossings are either uncontrolled (zebras) or light-controlled. In the case of the light-controlled crossings the anti-skid surfacing is usually applied at the time of installation of the crossing (see Section 2.5.12). This means that the introduction of the new surfacing is not the only significant change at the location and so a comparison of before-and-after accident rates is inappropriate. For this reason it was decided to exclude light-controlled pedestrian crossings from the study. Similarly, any individual site was rejected where other changes which could have affected the accident rate were known to have taken place during the accident study period. At the end of the selection process a total of 338 sites remained for further study:

- 211 zebra crossings (coded as TYPE 0)
- 108 light-controlled crossroads (TYPE 1)
- 19 light-controlled T or Y junctions (TYPE 2)

C Grid reference

The National Grid co-ordinates of the centre point of each site were recorded (to the nearest 10 metres). In the case of the pedestrian crossings these were obtained from the Metropolitan Police lists. For nodal juctions the information was extracted from the GASMAN network listing and for non-nodal junctions from the large-scale Ordnance Survey maps.

D <u>SFC values</u>

All the SFC values were obtained from the results of the routine survey of the skid resistance of the Principal road network in London which is conducted at approximately yearly intervals by the GLC Road Assessment Unit using the SCRIM test vehicle. It would be desirable to use the SFC values obtained at each site during the actual before and after periods. However, the 'before' values are not available for many of the early sites and there are also doubts (for a number of reasons) about the reliability of some of the results obtained during the first few surveys. Accordingly, it was decided to use only the 1984 survey results, with each reading being adjusted for seasonal and year-to-year variation (and other effects) to give a best-estimate equilibrium mean summer SFC value.

For the 'after' readings the value recorded (coded SFCSG) was the mean of the four readings (i.e. 40 metres) on the approach to each site. At junctions where more than one approach road was tested the value for the major road only was used. In the few cases where the SFC readings were not valid because the test speed was too low the 1983 values were substituted.

At a small proportion of the sites the mean SFC value on the anti-skid surfacing was substantially below the average of 0.65. Sixteen out of the 338 sites were found to have a mean SFC value of 0.55 or less. Examination of these sites (either from the video film or actual site inspection) revealed that in all cases the anti-skid surfacing had partially stripped or worn away, exposing the underlying conventional surfacing. It was considered that the present condition of these sites was unlikely to be representative of the condition in the three years immediately after treatment and so each was assigned the average SFC value. The SFC values at all 338 sites were re-entered as SFCSGC, incorporating this adjustment at the 16 sites.

Assessment of the SFC before treatment is more involved. The general assumption is made that the present SFC (i.e. the SFC measured in 1984) of the existing surface ahead of and beyond each treated section is not significantly different from the SFC at the time of treatment. The 'before' SFC on the 40-metre approach to the pedestrian crossing or junction (coded SFCB) is then estimated from the present mean SFC values on the 40m ahead of (SFC1) and beyond (SFC2) the approach.

A survey was carried out to establish whether the SFC on the 40m approach could be estimated reliably from readings on the abutting sections of road. Values of SFCB, SFC1 and SFC2 were obtained for all conventionally-surfaced uncontrolled pedestrian crossing sites in six representative boroughs - a total of 114 sites. The parameters SFC1, SFC2, mean of SFC1 and SFC2, and lowest from SFC1 and SFC2 were examined as predictors of SFCB. The best predictor variable was found to be the mean of SFC1 and SFC2, giving a mean difference of only 0.0007 with a standard deviation of 0.02. Accordingly, for each treated site the values equivalent to SFC1 and SFC2 were recorded so that the estimated SFC before treatment (SFCB) could be calculated.

E <u>Roadside land use</u>

Using the video film of the road network the pattern of land use at each location was assessed and was classified into four categories:

- HOUSING (coded 1)
- SHOPS (2)
- COMMERCIAL (3)
- OPEN (4)

The land use category recorded is not necessarily the category constituting the highest proportion of the frontage but is the category judged (in the light of the findings in Chapter 6) to be dominant in terms of accident risk at the particular site. Thus, a site consisting of 40% shops and 60% housing would be coded (2) because the accident rate would be determined largely by the presence of the shops.

F <u>Traffic flow</u>

Estimates of total daily flow (both directions) at each site were obtained from GLC Traffic Survey Section records. The estimates are based mainly on short sample counts but are believed to be accurate to within 10%. For the pedestrian crossing sites just one traffic flow value (coded TRAFFIC and estimated in thousands) was recorded. For the light-controlled junctions the major road flow (TRAFFIC) and minor road flow (TRAFFIC2) were recorded. At a small number of junction sites no figures were available for the minor road flow and it was necessary to make a coarse estimate based on known flows on comparable roads in the locality.

G <u>Accident data</u>

Accident totals were extracted from ACCSTATS using a computer program written by the GLC Road Safety Section (and unfortunately not available at the time that the work described in Chapters 5 and 6 was carried out). This gives before and after accident numbers (for pre-defined classes of accident) x years before and x years after a given year, within y metres of a defined point. This is especially useful for extracting details of accidents within a portion of a link. The program was used to list the numbers of accidents occurring within 50 metres of the centre of each site in the three years before treatment in the following categories:

- accidents in all conditions	(coded TOTACCB)
- dry-road accidents	(DRYACCB)
- wet-road accidents	(WETACCB)
- wet-road skidding accidents	(WETSKDB)
- wet-road shunts	(WETSHNTB)
- pedestrian accidents	(PEDACCB)

and the same categories in the three years after treatment, coded:

TOTACCA, DRYACCA, WETACCA, WETSKDA, WETSHNTA, PEDACCA

Using the basic accident data the following variables were computed:

PCWETB	- % wet before treatment
PCWETA	- % wet after treatment
PCSKIDB	- % wet-road skid before treatment
PCSKIDA	- % wet-road skid after treatment
PCSHNTB	- % wet-road shunt before treatment
PCSHNTA	- % wet-road shunt after treatment
XSWET	- excess wet-road accidents (see Sect. 6.3.3)

ACCRAT - accidents per million vehicle km

WETRAT - wet-road accidents per million vehicle km

SKRAT - wet-road skidding accidents per million veh. km

SHUNTRAT - wet-road shunts per million vehicle km

Additional computed variables are discussed below.

7.2.3 Control sections.

In investigating the effect of any treatment it is essential to consider what changes in accident rate might have occurred if the treatment had not been given. To do this it is necessary to select control cases which are similar in character to the treated cases and to observe changes in the controls and then adjust the results from the treated cases accordingly. The control cases may be matched to individual treated cases ('matched pairs') or may be combined to form a control group. In the field of accident investigation it is extremely difficult to match individual treated and untreated sites because it is rare for two sites to be sufficiently similar in terms of layout, traffic flow, skid resistance, accident pattern, etc. Furthermore, if a candidate control site does match a treated site then it follows that the candidate site itself merits treatment which would have to be deliberately withheld for the whole of the after period. It is, therefore, the usual practice to select a broad category of sites as a control group, e.g. if a group of junctions is treated then the control group might be all the junctions in the same geographical area. This method is suitable for compensating for the effects (which are usually relatively small) of general accident trends between the before and after periods but not for the frequently more important regression-to-mean effect. The latter effect has long been recognised (e.g. 102) and is particularly important when the treated sites are major accident black spots. The argument is that if accident rates in a given period at individual sites in the same category are examined then certain sites will be identified as black spots but the true long-term accident rates at some of these sites are actually closer to the group mean rate and in the subsequent period are more likely to regress towards the mean value than to stay at the higher level. If these sites had been treated as a consequence of their observed high rate then the effects of the treatment would have been over-estimated because at least part of the reduction in accidents would have occurred regardless of the treatment. The converse also holds, i.e. low accident rate sites are likely to have higher accident rates in a subsequent period, but this is of less significance because such sites are much less likely to receive remedial treatment.

The existence of the very large GLC accident data bank made it possible to devise a method to compensate for both of the effects described above. A computer file was created containing accident totals for each year from 1970 to 1983 for each of the 4161 nodes in the network. GLC Road Assessment Unit records were examined to identify nodes which are at light-controlled intersections (ATS junctions) and those at which there is an uncontrolled pedestrian crossing within 50 metres. Two control site files were then created from the master file - an ATS file (968 sites) and a pedestrian crossing file (416 sites).

For each treated site a control group was selected from the appropriate file, consisting of all the nodes with the same number of accidents as the treated site in the three years before the treatment year. The mean number of accidents at the control sites in the three years after treatment is then the expected 'after' total (coded EXPTOT) at the treated site. The reduction in total accidents attributable to the treatment is the expected number minus the observed number:

$$\text{REDUCTN} = \text{EXPTOT} - \text{TOTACCB}$$

The procedure outlined above could have been followed for wet-road accidents but it was felt that the computer costs involved could not be justified. Instead, it was assumed that the change in wet-road total at an individual site would be proportional to the change in overall total at that site and the expected number of wet-road accidents (EXPWET) would be

$$\text{EXPWET} = \text{WETACCB} \times (\text{EXPTOT}/\text{TOTACCB})$$

Similar assumptions were made for the other accident categories.

7.2.4 Data Analysis

Detailed information on each of the 338 treated sites is given in Table 4 of Appendix E.

Table 5 of Appendix E gives a statistical summary (mean, minimum, maximum, standard deviation) of the parameters for all the sites and for the different site categories. Mean values of selected parameters are presented below in Table 7.1 showing accident rates before and after treatment.

On the basis of the regression equations developed in Sect.7.1 the predicted change in accident rate at each site was calculated. Mean values for the predicted and observed changes are compared in Table 7.2.

7.2.4.1 Change in skid resistance

The SFC before treatment ranged from 0.22 to 0.51 with a mean value of 0.35. The anti-skid treatment increased the SFC to an observed mean of 0.65, with values at individual sites ranging from 0.51 to 0.75. As noted in Section 7.2.2 the values in the range 0.51 to 0.55 (found at 16 sites) were considered to be unrepresentative of the values prevailing in the three years immediately following the application of the anti-skid surfacing and were adjusted to the mean value. The overall mean SFC after these adjustments had been made remained at 0.65.

It should be noted that before treatment only one of the 338 sites complied with the target SFC of 0.50 in the Giles and Marshall standards (category B sites) and none complied with the LR510 minimum requirement of 0.55 (for low-risk category A1 sites). After treatment all sites complied with the Giles and Marshall standards and there was substantial compliance with LR510.

TABLE 7.1

Accident rates before and after anti-skid treatment

(mean values for 338 sites)

ACCIDENT PARAMETER	BEFORE	AFTER		NET CHANGE	% NET CHANGE	SIGNIF.
		EXPECTED	OBSERVED			
TOTAL	16.444	15.168	13.459	-1.709	-11.27	***
WET-ROAD	4.962	4.579	2.982	-1.597	-34.88	***
DRY-ROAD	11.408	10.506	10.382	-0.124	- 1.18	NS
WET SKIDS	0.580	0.542	0.180	-0.362	-66.79	***
WET SHUNTS	0.775	0.717	0.473	-0.244	-34.03	***
PEDESTRIAN	5.825	5.376	4.864	-0.512	- 9.52	***
% WET	31.217	31.217	23.369	-7.848	-	***
% WET SKID	10.934	10.934	5.623	-5.311	-	***
ACC/mvkm	5.493	5.131	4.438	-0.693	-13.51	***
WET/mvkm	1.683	1.571	0.998	-0.573	-36.47	***

Note 1. *** = change significant at probability better than 0.001 (chi-square test based on accident numbers at all 338 sites)

Note 2. Expected 'after' value is 'before' value adjusted for changes in controls where appropriate.

7.2.4.2 Change in accident rates

A Total accidents

There was a mean of 16.44 accidents per site in the three years before treatment (with individual totals ranging from 0 to 61). Expressed in terms of traffic flow (and for junctions taking into account only the major road length and the major road traffic) this was 5.49 accidents per million vehicle km overall.

In the three-year period after treatment the mean accident total was 13.46, a reduction of 18.1%. However, accidents at the control sites were also lower, with a mean of 15.17. Thus, the net reduction at the treated sites (after allowing for changes at the control sites) is 1.71 which is equivalent to a reduction of 11.3%. The 95% confidence interval for the mean reduction is 1.08 to 2.34. and the change is statistically highly significant (probability better than 0.001).

There was an observed reduction in accidents at 232 treated sites, no change at 19 sites and an increase at 87. After allowing for the controls the net result is a reduction at 227 sites, no change at 2 and an increase at 109. It is to be expected that there will be increases at some sites due to chance fluctuations and little change at others because the accidents may be of a type for which an improvement in skid resistance is of no benefit, but the proportion of unsuccessful sites does seem to be unduly high. There is clearly a need to identify the characteristics of sites which will respond favourably to the anti-skid treatment and to develop better site-selection criteria.

B Wet-road accidents

A mean reduction of 1.98 was observed in the number of accidents occurring on wet roads. After adjustment for changes at the control sites this becomes a net reduction of 1.60 (34.9%) which is highly significant (probability better than 0.001). The 95% confidence interval for the net reduction is 1.28 to 1.91. In percentage terms this is equivalent to a reduction of 28.0% to 41.7% in wet-road accidents.

The mean Percentage Wet value fell from 31.22% to 23.37% (change significant at probability better than 0.001). The 95% confidence interval for the reduction is 5.43 to 10.27.

C Dry-road accidents

A net reduction of only 1.2% (not significant) was found in dry-road accidents . A reduction in dry-road accidents would not be expected because the skid resistance of the anti-skid surfacing is little different from that of conventional surfaces in the dry but a reduction was found in earlier London studies (91, 92) and was believed to be due to poor reporting of the road condition by the police (i.e. many of the 'dry' accidents were in reality 'wet'). The controls used in the earlier studies were much less sensitive than those in the present study and it is possible that the apparent substantial reduction reported in dry-road accidents was due at least partly to the regression-to-mean effect.

D Wet-road skidding accidents

There was a net reduction of 66.8% in reported wet-road skidding accidents at the treated sites (significant at probability better than 0.001).

Although the skid resistance before treatment at virtually all 338 sites would be considered low when assessed against the various proposed standards the incidence of skidding at these sites was very low. There was a mean of only 0.58 wet-road skidding accidents per site in the three years before treatment. At 213 of the sites there were no reported wet-road skidding accidents and the maximum number at any one site was only 5. The mean wet-road skidding rate before treatment was only 10.9%, falling to 5.6% after treatment. It should be noted that before treatment there was a grand total of only 196 wet-road skidding accidents. If this figure had been accepted as indicating the maximum number of accidents that could be prevented by improving the skid resistance then the accident savings would have been grossly underestimated. The net reduction of 578 accidents which was achieved is almost three times the number of reported skidding accidents in the pre-treatment period.

E <u>Wet-road shunt accidents</u>

The mean number of wet-road shunt accidents is also relatively small - only 0.93 (in three years before treatment). Wet-road shunts and wet-road skids are not mutually exclusive categories since a shunt accident may involve skidding. Wet-road shunts fell by an average of 33.9% (significant at probability better than 0.001).

F <u>Pedestrian accidents</u>

Accidents involving injury to pedestrians fell by a net 9.5% (significant at better than 0.001).

7.2.4.3 Predicted change in accident rate compared with actual change.

On the basis of the regression equations developed in Section 7.1 the predicted changes in accident rate at each of the experimental sites was calculated, using the before-and-after SFC values (SFCB and SFCSGC) and, where appropriate, traffic flow as predictor variables. All thirty regression equations were used irrespective of whether the coefficient of the SFC term had been shown to be significant. Predicted changes were calculated in total accidents and wet-road accidents (in three years), accidents per million vehicle km, wet-road accidents per million vehicle km and Percentage Wet.

Table 7.2 shows the mean observed change in each accident parameter (adjusted for changes in control sections) compared with the predicted change. An indication is given as to whether the coefficient of the the SFC term in the regression equation was significant. The table also shows the correlation coefficient for predicted change versus observed change at individual sites.

It will be seen that the correlation between predicted change and observed change at individual sections is extremely poor; none of the correlation coefficients are significant.

Although the mean predicted changes in accident rate are, in general, of the same order as the observed changes, it must be remembered that the confidence limits about the predictions are very wide (see Section 7.1). In most cases the mean observed change is

TABLE 7.2

Comparison of predicted and observed changes in accident rate resulting from increase in skid resistance.

ACCIDENT PARAMETER	REGRESSION EQUATION			MEAN CHANGE		CORRELATION AT INDIVIDUAL SITES
	no.	signif.	type	predicted	observed	r
total accidents (TOTACC)	R 1	-	LIN	-2.16	-1.71	0.0548
	R11	*	LIN	-2.44		0.0548
	R 6	-	CUR	-1.21		0.0424
	R16	*	CUR	-1.52		0.0424
	R21	*	POL	-2.88		0.0601
	R26	*	LOG	-1.99		-0.0412
wet-road accidents (WETACC)	R 2	*	LIN	-1.87	-1.60	-0.0180
	R12	*	LIN	-1.25		-0.0180
	R 7	*	CUR	-0.97		-0.0398
	R17	*	CUR	-0.86		-0.0398
	R22	-	POL	-0.77		-0.0352
	R27	*	LOG	-0.57		0.0046
% wet (PCWET)	R 3	-	LIN	-15.63	-7.85	-0.0373
	R13	*	LIN	-19.57		-0.0373
	R 8	-	CUR	- 7.53		-0.0768
	R18	*	CUR	-13.05		-0.0768
	R23	-	POL	-26.93		-0.0003
	R28	-	LOG	- 7.55		0.0116
accidents per mill. vehicle km (ACCRAT)	R 4	-	LIN	-0.85	-0.69	0.0490
	R14	*	LIN	-1.16		0.0490
	R 9	-	CUR	-0.51		0.0305
	R19	*	CUR	-0.73		0.0305
	R24	-	POL	-1.53		0.0680
	R29	*	LOG	-0.59		0.0293
wet-road accidents per mill. vehicle km (WETRAT)	R 5	*	LIN	-0.76	-0.57	-0.0550
	R15	*	LIN	-0.56		-0.0550
	R10	*	CUR	-0.39		-0.0759
	R20	*	CUR	-0.38		-0.0759
	R25	-	POL	-0.47		0.0699
	R30	*	LOG	-0.29		-0.0752

Note 1. * indicates significant coefficient for SFC term in regression equation.

Note 2. Regression models (see Sect.7.1)

LIN... $A = B_1(TRAFF) + B_2(SFC) + C$

CUR... $A = B_1(TRAFF) + B_2/(SFC)^2 + C$

POL... $A = B_1(TRAFF) + B_2(SFC) + B_3(SFC)^2 + C$

LOG... $A = C\ (TRAFF)^p(SFC)^q$

Note 3. r is correlation coefficient for predicted v. observed change at each of 338 sites (correlation significant at 0.05 level if r exceeds 0.090).

Note 4. Values for observed changes have been adjusted to allow for changes in control sections.

within the 95% confidence interval for the prediction but that interval is so wide that the finding is of little value. Furthermore, a number of the predictions (e.g. R21, R2, R12, R17, R22) are unrealistic because the predicted reduction is equivalent to more than 100% of the original accident rate in the study sections (i.e. the links and the Borough B sections) for which the regression equations were derived. This highlights one of the limitations of the use of the regression technique for predicting the effect of changes in one of the independent variables, viz. that since the SFC values in the experimental group of sites were increased to levels which were outside the range of the experimental study group, the predictions involve extrapolation beyond the range for which the regressions are valid as defining associative relationships. It would have been desirable to have examined sites where the SFC changes were within the SFC regression limits but an insufficient number of such sites was available. It would also have been desirable to have studied treated sites where the overall average accident rate was similar to the average for the regression study group; mean accident rates at the experimental sites were substantially higher than at the study group sites.

Once again it must be emphasised that the variance is so high and the regression equations so imprecise that it has not been possible to prove or disprove the validity of any of them. Clearly, further work is necessary but it would need to be a very large-scale study to have a reasonable probability of producing conclusive results. The important finding, about which there is no doubt, is that increasing the skid resistance at the experimental sites to the highest practicable level produced a substantial reduction in wet-road accidents (mean reduction 34.9%, with standard error equivalent to 3.5%) and this provides a basis for estimating the potential accident savings on urban roads generally.

7.3 SUMMARY.

1. Regression equations were developed defining the relationship between SFC and accident rate.

2. Although the relationships were statistically significant, they are of limited predictive value because of widely-spaced confidence limits.

3. The correlation was disappointingly poor between observed change in accident rate at individual sites, following an increase in skid resistance, and change predicted by the regression equations.

4. At 338 sites where the skid resistance was increased to the highest practicably-attainable level there was an overall reduction of 34.9% in wet-road accidents.

5. The overall reduction in accidents was equal to approximately three times the number of wet-road skidding accidents reported before treatment. This indicates that the potential accident saving is much greater than skidding accident statistics alone would suggest.

6. At a substantial proportion of sites where the skid resistance was very low the accident rate was not unduly high. This indicates that at some locations skid resistance has no appreciable influence on accident rate. This is supported by the fact that at about one-third of the experimental sites the improved skid resistance did not reduce the accident rate.

CHAPTER 8

ESTIMATION OF OVERALL POTENTIAL SAVING IN ACCIDENTS AND SELECTION OF SITES FOR ANTI-SKID TREATMENT

8.1 ACCIDENT REDUCTION FROM ATTAINMENT OF MAXIMUM SFC

In Chapter 7 it was established that increasing the SFC at the approaches to 338 uncontrolled pedestrian crossings and light-controlled junctions in London produced a net reduction of 34.9% in wet-road accidents. The increase in SFC at these sites (referred to as the 'experimental' sites) was achieved by the use of an epoxy resin/calcined bauxite surface dressing (described in Chapter 4) which gives the maximum SFC practicably attainable. The mean SFC was 0.35 before treatment and 0.65 after treatment.

At braking and turning areas such as pedestrian crossings and light-controlled junctions the SFC on conventional surfaces is generally lower than elsewhere because of the additional polishing stresses. At the link sites (see Chapter 7), which are more representative of classified roads in London, the mean SFC was higher, at 0.42. It has been observed that the SFC obtained with calcined bauxite (unlike other aggregates) does not depend greatly upon traffic intensity and, therefore, the SFC obtained with resin/bauxite on typical sections of road no more than marginally exceeds the value of 0.65 measured at the high-stress locations. Thus, use of the resin/bauxite anti-skid treatment throughout the classified road network in London would increase the overall SFC level by a minimum of 0.23 (compared with a mean increase of 0.30 at the experimental sites).

Little is known of the level of SFC on urban roads outside London because highway authorities are, understandably, reluctant to publish such information. Traffic levels (and hence polishing stresses) are higher in London than elsewhere and it might be expected that SFC levels would be lower. However, the effect of the greater traffic stresses is offset by the use in the GLC area of roadstones with PSV higher than those in general use elsewhere. Thus, it is reasonable to assume that average SFC levels on urban classified roads in Britain are no higher than those found in London.

On unclassified roads in urban areas traffic stresses are generally low and there is rarely any technical difficulty in maintaining a high skid resistance. Accident densities are low (see Chapter 2) and consequently there is relatively little scope for accident saving by improving SFC on these roads except in a few isolated cases.

In 1980 in London 83% (38,153) of all accidents and 85% (10,194) of wet-road accidents were on classified roads. In urban areas generally 58% (111,382) of all accidents were on classified roads. Assuming that 58% of the urban total of 62,192 wet-road accidents were on classified roads gives a national total of 36,071 wet-road accidents on classified roads.

If the full reduction of 34.9% achieved at the experimental sites is achieved throughout the urban classified road network the reduction in accidents (based on 1980 statistics) will be:-

12,589 accidents per annum nationally
3,558 accidents per annum in London.

The 95% confidence limits about the estimates are ± 19.6% of the stated reduction. (see 7.2.4).

If it is assumed that since the mean increase in SFC will not be as great as at the experimental sites (0.23 instead of 0.30) then the accident reduction will be less, and if it is further assumed (see 8.2) that the reduction will be directly proportional to the increase in SFC then the accident savings estimated above are reduced to:-

9,652 accidents per annum nationally
2,752 accidents per annum in London

Thus, anti-skid treatment of the whole of the urban classified road network would give an estimated saving in accidents of 9,652 per annum. This reduction represents:-

26.8% of wet-road accidents on urban classified roads
15.5% of wet-road accidents on urban roads generally
5.0% of all urban accidents
3.8% of accidents nationally

8.2 ACCIDENT REDUCTION FROM INCREASE OF 0.10 IN SFC

The previous section dealt with the estimation of the potential accident saving that could result from increasing the SFC to the maximum that is technically feasible, i.e. by the use of resin/bauxite surface dressing. However, that process is expensive and calcined bauxite aggregate of the required quality is in short supply. It is most unlikely that any urban highway authority would have sufficient funds to be able to use it throughout the main road network. It was suggested in Chapter 4 that better use could be made of readily-available conventional materials and that by improving materials specifications, materials selection and standards of workmanship an increase of 0.10 in SFC is achievable at little or no additional cost. It had been hoped that the regression studies described in Chapter 7 would provide a basis for estimating the resultant saving in accidents. The regression equations proved to be unsatisfactory for this purpose but observed changes at the experimental sites provide an alternative. It was found that an average increase of 0.30 in SFC produced a reduction of 34.9% in wet-road accidents. The accident reduction resulting from an intermediate increase in SFC depends upon the relationship between accident rate and SFC, and this is ill-defined. However, a first-order estimate may be made by assuming that the percentage reduction in wet-road accidents per unit increase in SFC is constant. On this basis the reduction in accidents achievable by increasing SFC by 0.10 on urban classified roads is estimated to be:-

4,196 accidents per annum nationally
1,185 accidents per annum in London.

This is equivalent to a reduction of

11.6% in wet-road accidents on urban classified roads
6.7% in wet-road accidents on urban roads generally
2.2% of all urban accidents
1.7% of accidents nationally

8.3 SELECTION OF SITES FOR ANTI-SKID TREATMENT

8.3.1 Identification of characteristics of sites which will respond favourably to treatment

As suggested in the previous section, with limited resources it is unrealistic to expect highway authorities to be able to treat the entire network with anti-skid surfacing. It is likely that the use of resin/bauxite (and other expensive anti-skid treatments) will continue to be confined mainly to localised areas of high accident risk. Consideration must, therefore, be given to selecting sites where an improvement in skid resistance will be most effective in reducing accidents.

At a substantial proportion of the experimental sites it was found that the treatment was not effective in reducing the number of accidents. This suggests that at some locations the skid resistance has no influence on accident rate. It is important to be able to identify such locations and to ensure that the funds that are available are used at sites where the greatest accident savings are likely.

(i) Performance criteria

The most general measure of the effectiveness of an anti-skid treatment at a particular location is the overall saving in total accidents (i.e. personal-injury accidents of all types). This is denoted (as in Chapter 7) by REDUCTN which is the net reduction in accidents (after allowing for changes in control sections) in the three years after treatment.

At some point it is necessary to consider the cost of treatment in relation to the accident savings and this is discussed in Chapter 9. A useful parameter for this purpose is REDPM which is the accident reduction in three years per thousand square metres treated (i.e. REDUCTN divided by area in thousands of square metres). Values of REDPM were calculated for each experimental site using average area figures of $1000m^2$ for light-controlled junctions and $550m^2$ for pedestrian crossings.

The treatment at an individual site could be considered successful if it produces a reduction, however small, in accidents (i.e. if REDUCTN > 0) but for reasons which are explained in Chapter 9 the resin/bauxite treatment may be considered a success in economic terms only if REDPM > 0.38. On this basis it is found that there was a reduction in accidents at 227 (67.2%) of the 338 sites, of which 207 (61.2%) were economically successful. Clearly, there is a need to refine the site selection criteria to increase the success rate.

(ii) Possible selection criteria

A. Skid resistance

In deciding whether the skid resistance at a particular site is low it is usually compared either with the target values in one of the proposed sets of standards or with the values found at similar sites in the network. As noted earlier, at only one of the 338 experimental sites did the SFC before treatment comply with the Marshall Committee target of 0.50 (for Category B sites - Trunk and Principal roads in urban areas) and none was within the range 0.55 to 0.75 suggested in LR510 (Category A1(ii) - approaches to traffic signals, pedestrian crossings and similar hazards on main urban roads). Thus, compared with the proposed standards the SFC at all of the experimental sites would be considered low. Compared with other conventially-surfaced category A1(ii) sites in London (e.g. the pedestrian crossings encountered in the Borough B study) they are not untypical.

The range of SFC values was quite wide (0.22 to 0.51). Sorting the sites in terms of SFC and examining the upper and lower quartiles it was found that the success rate (i.e. the proportion of sites for which REDPM was 0.38 or more) was 70.6% in the high-SFC quartile and 69.4% in the low-SFC quartile (difference between two groups not significant). This suggests that selecting sites for treatment on the basis of low SFC alone is no better than selecting sites at random.

A useful statistical method of judging the effectiveness of a selection parameter in ranking sites in the appropriate order is the Kendall Rank Order Correlation technique. This involves sorting the sites on the basis of the performance parameter (REDPM) and on the basis of the selection parameter (e.g. SFC, PCWET), then comparing the ranks. From the differences between ranks the Rank Correlation

Coefficient, tau, is calculated (which is analagous to the r value used in earlier chapters for investigating the degree of correlation between variables). Using this procedure for comparing rankings of SFC and REDPM gave a tau value of -0.0173 (with associated probability, p = 0.320). This indicates that ranking on SFC is not significantly better than a random order and confirms that SFC alone is an extremely poor selection parameter.

Ranking in terms of SFC deficit might also be considered, i.e. the difference between the target SFC value and the actual value, but, since in this instance all the 'before' SFC values are below the target level, the deficit is the complement of the SFC and the result would be identical.

In considering whether there is a need to increase the SFC at a particular site, perhaps the question ought to be not whether the existing SFC is low in relation to the standards or to similar sites in the area but whether it is low in relation to the needs of that site. This is best assessed by examining the accident history of the site. An equally pertinent question, also involving examination of the accident records, is whether (regardless of present SFC level) improving the SFC might reduce the accident rate.

B Skidding accident parameters

An obvious selection parameter is PCSKID, the percentage of wet-road accidents in which skidding was reported. If the Percentage Skidding is above average then that is a good indication of the need for an improvement in skid resistance and, of course, that the improvement is likely to reduce the accident rate. As with all percentage parameters, percentage skidding is subject to distortion when small numbers of accidents are involved and it is advisable to perform a chi-squared test to establish whether the Percentage Skidding is significantly higher than average.

Chi-squared values (CHISKID) were calculated for all the experimental sites and thirty sites were found to have a Percentage Skidding significantly above the London average (taken as 10%). At these sites the success rate was 86.7% which is much higher than the overall success rate of 63.6% at the remaining sites (difference significant at probability 0.05).

The mean reduction in total accidents at the high skid-rate sites was 3.80 compared with 1.51 (difference significant at 0.05 probability level). Thus, there are strong indications that the selection of sites with Percentage Skidding significantly above average is a reliable method. The weakness of this criterion is that only a small number of suitable sites are identified. Out of 338 sites 30 were selected, of which 25 were successful, but 182 successful sites would have been passed over.

Using CHISKID (the chi-squared value for Percentage Skid) as a ranking parameter gave a rank correlation coefficient, tau, of 0.1316 (significant at better than 0.001) which indicates that it could be suitable (regardless of its significance in relation to the average Percentage Skid) as a selection criterion.

Tau values for four possible skidding parameters are shown below:

	tau	p
PCSKID, percentage skidding	0.1290	< 0.001
CHISKID, chi-squared value derived from PCSKID	0.1316	< 0.001
WETSKID, number of wet-road skidding accidents	0.1307	< 0.001
SKRAT, wet-road skidding accidents/mvkm	0.1289	< 0.001

It will be seen that there is little difference between any of the skidding parameters as selection criteria if based on the ranking method.

At sites where there were one or more reported skidding accidents before treatment the mean reduction in accidents was 2.78 compared with 1.08 at sites where there were no skidding accidents (difference significant at probability 0.01). At sites with two or more skidding accidents compared with sites where there were none the differences were even more marked (reduction of 3.23 compared with 1.08, difference significant at better than 0.05).

The success rate at the skidding sites was higher than at the remaining sites (70.4% compared with 60.6%, difference significant at probability 0.01).

It might be considered advisable to confine the anti-skid treatment to sites where skidding accidents have been reported. If this had been done at the experimental sites then 58.1% of the successfully treated sites would have been missed.

C Wet-road accident parameters

It was found in Chapter 5 that at all of the London skidding accident black spots examined the proportion of accidents occurring in the wet was much higher than average and this suggested that Percentage Wet (PCWET) might be a useful indicator of the adequacy of the skid resistance at a particular location.

At 90 (26.6%) of the experimental sites the Percentage Wet was found to be significantly greater than average (taken as 25% for London) and at these sites the success rate was 77.8% compared with 61.3% at the remainder (difference significant at probability 0.01).

The mean REDUCTN at the 90 high-wet sites was higher than at the remaining sites (2.84 compared with 1.30, difference significant at probability 0.05).

Of the wet-road parameters shown below, XSWET and PCWET are the best ranking parameters.

	tau	p
PCWET, percentage on wet roads	0.0877	0.009
CHIWET, chi-squared value derived from PCWET	0.0793	0.021
WETACC, number of wet-road accidents	0.0533	0.081
XSWET, excess wet-road accidents (over expected no.)	0.0946	0.005
WETRAT, wet-road accidents/million vehicle km	0.0848	0.010

D Wet-road shunt parameters

Nose-to-tail accidents frequently involve skidding which is undetected. A high incidence of shunts at a site could be an indication of the need for an improvement in skid resistance. At the 18 sites where the wet-shunt proportion was significantly higher than average (taken as 15%) the success rate was higher than at the remaining sites (77.8% compared with 64.4%) but, owing to the small number of high shunt rate sites involved, the difference is not shown to be significant.

The tau values for the four shunt parameters shown below indicate that they are all potentially good ranking parameters.

	tau	p
PCSHNT, % involving nose-to-tail collision	0.0650	0.052
CHISHUNT, chi-squared value derived from PCSHNT	0.0659	0.052
WETSHNT, number of nose-to-tail collisions	0.0737	0.039
SHNTRAT, nose-to-tail acc. per million veh. km	0.0882	0.013

E Regression equations

The regression equations developed in Chapter 7 were shown to be very poor predictors of actual reduction but it is worth considering whether predicted reduction is of any value as a ranking parameter. Each of the regression equations R1 to R30 was used to calculate predicted accident reduction resulting from the increase in SFC at each experimental site. Rankings for actual and predicted reductions were then compared and the rank correlation coefficients calculated. From the tau values shown in Table 8.1 it will be seen that none of the regression equations shown generates a satisfactory ranking parameter (at the $p = 0.05$ level).

TABLE 8.1

Comparison of regression equations as

generators of ranking parameters

REGRESSION EQUATION	ALL SITES		ATS JUNCTIONS		PEDESTRIAN CROSSINGS	
	tau	p	tau	p	tau	p
R1	0.0555	0.066	0.0466	0.221	0.0523	0.133
R2	0.0557	0.066	0.0464	0.223	0.0523	0.133
R3	0.0543	0.070	0.0448	0.230	0.0508	0.139
R4	0.0553	0.066	0.0461	0.223	0.0519	0.134
R5	0.0556	0.065	0.0462	0.223	0.0521	0.133
R6	0.0263	0.236	0.0202	0.369	0.0281	0.272
R7	0.0263	0.236	0.0202	0.369	0.0281	0.273
R8	0.0263	0.236	0.0202	0.369	0.0281	0.272
R9	0.0263	0.236	0.0202	0.369	0.0281	0.272
R10	0.0263	0.236	0.0202	0.369	0.0281	0.272
R11	0.0555	0.066	0.0453	0.228	0.0525	0.132
R12	0.0546	0.069	0.0453	0.228	0.0508	0.140
R13	0.0550	0.068	0.0460	0.225	0.0514	0.137
R14	0.0562	0.064	0.0474	0.218	0.0525	0.131
R15	0.0556	0.065	0.0462	0.223	0.0521	0.133
R16	0.0263	0.236	0.0202	0.369	0.0281	0.272
R17	0.0263	0.236	0.0202	0.369	0.0281	0.272
R18	0.0263	0.236	0.0202	0.369	0.0281	0.272
R19	0.0263	0.236	0.0202	0.369	0.0281	0.272
R20	0.0263	0.236	0.0202	0.369	0.0281	0.272
R21	0.0565	0.061	0.0441	0.232	0.0530	0.127
R22	0.0167	0.324	0.0206	0.366	0.0170	0.357
R23	0.0481	0.094	0.0441	0.232	0.0421	0.182
R24	0.0511	0.081	0.0466	0.220	0.0450	0.167
R25	0.0416	0.128	0.0351	0.280	0.0403	0.193
R26	-0.0445	0.111	-0.0373	0.267	-0.0357	0.221
R27	-0.0364	0.160	-0.0316	0.300	-0.0253	0.293
R28	-0.0347	0.171	-0.0256	0.335	-0.0271	0.280
R29	0.0308	0.200	0.0247	0.347	0.0329	0.240
R30	0.0295	0.210	0.0222	0.356	0.0318	0.247

Note 1 Ranking parameter is predicted reduction in accident rate calculated from regression equation.

Note 2 Tau = Kendall Rank Correlation Coefficient
p = probability that ranking order is random

(iii) Differences between parameters according to type of site

The sensitivity of some of the accident parameters varies according to the type of site. In Table 8.2 the rank correlation coefficients are compared for light-controlled junctions and pedestrian crossings. It will be seen that the skidding accident and wet-road parameters are more sensitive at pedestrian crossings and that the shunt parameters are more sensitive at light-controlled junctions.

TABLE 8.2

Comparison of ranking parameters for selection of sites for skid resistance improvement

SELECTION PARAMETER	ALL SITES		ATS JUNCTIONS		PEDESTRIAN CROSSINGS	
	tau	p	tau	p	tau	p
SFC	-0.0173	0.320	-0.0128	0.417	-0.0214	0.324
PCSKID	0.1316	<0.001	0.0840	0.107	0.1531	0.002
CHISKID	0.1316	<0.001	0.0840	0.107	0.1531	0.002
WETSKID	0.1307	<0.001	0.1048	0.066	0.1581	0.002
SKRAT	0.1289	<0.001	0.1160	0.041	0.1401	0.004
PCWET	0.0877	0.009	0.0702	0.122	0.1101	0.010
CHIWET	0.0793	0.021	0.0685	0.139	0.0919	0.032
XSWET	0.0946	0.005	0.0796	0.095	0.1157	0.007
WETACC	0.0533	0.081	0.0975	0.059	0.1183	0.008
WETRAT	0.0848	0.010	0.1447	0.008	0.1185	0.006
PSCSHNT	0.0650	0.052	0.0927	0.077	0.0501	0.165
WETSHNT	0.0737	0.039	0.1182	0.041	0.0672	0.106
SHNTRAT	0.0882	0.013	0.1400	0.015	0.0685	0.089

Note 1 Performance parameter is REDPM (accident reduction per 1000 square metres treated) in three years after treatment

Note 2 Tau = Kendall Rank Correlation Coefficient
p = probability that ranking order is random

(iv) <u>Use of discriminant analysis to examine combinations of selection parameters.</u>

Hitherto, possible selection parameters have been considered in isolation. A procedure available in the SPSS package is Discriminant Analysis which may be used to statistically distinguish between two groups of cases (in this instance the 'best' and 'worst' sites in terms of accident reduction per unit area of treatment). The procedure involves the examination of a collection of discriminating variables (i.e. the selection parameters) in order to weight and linearly combine them in such a way as to discriminate between the two groups. A 'discriminant function' is produced, of the form

$$D = d_1 z_1 + d_2 z_2 + \ldots\ldots d_n z_n$$

where D is the score on the discriminant function

d_1, d_2, ... d_n are weighting coefficients

z_1, z_2, ... z_n are the standardised values of the n discriminating variables used in the analysis.

The analysis attempts to form a discriminating function such that within each group the members have discriminant scores which are similar and are different from those in the other group. Once a set of variables is found which provides satisfactory discrimination for cases with known group membership the derived discriminant function may be used to classify other cases with unknown group membership. For the initial analysis a stepwise procedure is used to select variables on the basis of their discriminating power (in a similar way to the procedure used in the multiple regression analyses in Chapt.6). Variables are added sequentially to the equation with, at each stage, the added variable being the 'next best' discriminator (given the variables already selected). The selection process ceases either when all the variables are included or the remaining variables would not improve the discriminating power. This leads to the exclusion of a variable which is highly correlated with a variable already included, e.g. if Percentage Skid (PCSKID) is selected then Chi-squared for Percentage Skid (CHISKID) would probably be rejected.

The two groups used for the analysis stage were the upper and lower REDPM quartiles. Separate analyses were performed for all sites (338 cases), light-controlled junctions (127 cases) and pedestrian crossings (211 cases). The input variables were :

SFCB

PCSKIDB,CHISKID,WETSKDB,SKRATB

PCSHNTB,WETSHNTB,SHNTRATB

PCWETB,CHIWET,WETACCB,WETRATB,XSWET

TOTACCB

TRAFFIC

The analysis for all sites resulted in the variables

CHISKID,SHNTRATB and TRAFFIC

being selected as the optimum set of discriminant variables. Note that SFCB was rejected. The discriminant function is

D = 0.192(CHISKID) + 1.693(SHNTRATB) - 0.077(TRAFFIC) + 1.559

The mean scores obtained for the two groups using this function were

group A (best) = 0.354

group B (worst) = -0.354

Membership of one or other group may be predicted on the basis of the discriminant score. Classifying the original set of cases in this way gives the results shown below.

ACTUAL GROUP	NO. OF CASES	PREDICTED GROUP MEMBERSHIP	
		group A	group B
group A (best)	85	48	37
		(56.5%)	(43.5%)
group B (worst)	85	22	63
		(25.9%)	(74.1%)

The predicted classification was correct for 111 (65.3%) of the sites. It is interesting to note that the predictions are substantially better for group B sites. These results indicate that the discriminant function is not particularly good for selecting the most worthwhile sites for treatment but is more successful in identifying sites where treatment is least likely to be effective in reducing accidents.

The separate analysis for the light-controlled junctions gave

PCSKIDB, SHNTRATB, CHIWET, WETRAT

as the optimum set of discriminating variables, with the discriminant function

D = 0.029(PSKIDB)+2.098(SHNTRATB)-0.090(CHIWET)+0.569(WETRATB)-1.812

The mean discriminant scores were

group C (best) = 0.537

group D (worst) = -0.505

Actual and predicted group membership is shown below.

ACTUAL GROUP	NO. OF CASES	PREDICTED GROUP MEMBERSHIP	
		group C	group D
group C (best)	32	22 (68.8%)	10 (31.3%)
group D (worst)	34	10 (29.4%)	24 (70.6%)

Thus, 46 (69.7%) of the sites are correctly classified; an improvement on the equivalent proportion of 65.3% for the all-sites analysis. The proportion classified correctly is very similar for group C and group D

For the pedestrian crossing sites the optimum discriminating variables were

CHISKID, SFCB, WETRATB, TOTACCCB

with the discriminant function

D = 0.173(CHISKID) - 7.323(SFCB) + 0.766(WETRATB) and mean discriminant scores

group D (best) = 0.374

group E (worst) = -0.348

giving the classification results shown below.

ACTUAL GROUP	NO. OF CASES	PREDICTED GROUP MEMBERSHIP	
		group E	group F
group E (best)	54	27 (50.0%)	27 (50.0%)
group F (worst)	58	14 (24.1%)	44 (75.9%)

Seventy-one (63.4%) of the sites were classified correctly but there is a marked difference between the two groups. The classification is excellent for group F (worst) sites but for the group E (best) sites it is extremely poor, being no better than a random selection.

(v) Empirical selection criteria.

The results of the discriminant analyses in the previous section showed that the procedure provided a useful means of identifying sites where an improvement in skid resistance was least likely to be effective in reducing accidents but it was not satisfactory (especially at pedestrian crossing sites) for positively identifying suitable sites for treatment. In this section consideration is given to the use of empirical combinations of parameters. The suggestion is examined that a site should be treated only if the accident records for the previous three years show that there is evidence of a wet-road accident problem and/or a wet-road skidding problem and/or a wet-road shunt problem. Conversely, a site should not be treated if there is evidence that there are none of these problems.

Evidence of a wet-road problem is :

- Percentage Wet significantly above average (i.e. CHIWET > 3.84)

  <u>OR</u>

- XSWET in upper quartile

  <u>OR</u>

- WETRAT in upper quartile.

Evidence of a wet-road skidding problem :

- One or more wet-road skidding accidents reported.

Evidence of a wet-road shunt problem :

- One or more wet-road shunt accidents.

Evidence that there is not a wet-road problem :

- WETRAT in lower quartile

  <u>AND</u>

- XSWET zero.

Evidence that there is not a skidding problem :

- No wet-road skidding accidents.

Evidence that there is not a wet-road shunt problem :

- No shunts reported.

Table 8.3A shows various combinations of accident indicators in relation to success rate and REDPM at the experimental sites. The treatment was successful (i.e. REDPM > 0.38) at 65.7% of the sites and the mean value of REDPM was 2.61. At sites where the SFC before treatment was low (defined in this context as SFC < 0.31 which is the lower quartile SFC value) the success rate is 68.8% which is not significantly different from the rate at the remaining sites. The success rate is higher at sites where there is a positive indication of an associated accident problem, except for the wet-shunt group, where it is slightly lower (but see later comments) and higher still where there is more than one positive accident indicator. The highest success rate (80.4%) was at the group of 51 sites with all three positive accident indicators present. A similar pattern emerges when mean values of REDPM are examined.

TABLE 8.3 A

Comparison of grouped selection parameters

for anti-skid surface treatment sites

(338 sites)

GROUP A. POSITIVE ACCIDENT INDICATORS

LOW SFC	WET-ROAD ACCIDENT PROBLEM	WET-ROAD SKIDDING PROBLEM	WET-ROAD SHUNT PROBLEM	NO. OF SITES	SUCCESS RATE		REDPM	
					%	signif.	mean	signif.
•				80	68.8	NS	3.21	NS
	•			136	75.0	**	4.54	**
		•		125	74.4	**	4.24	**
			•	162	68.5	NS	3.17	NS
•	•			29	72.4	NS	4.13	NS
•		•		32	78.1	NS	4.53	NS
•			•	40	75.0	NS	4.08	NS
	•	•		76	77.6	*	5.03	**
	•		•	82	76.8	*	5.05	**
		•	•	82	78.0	**	4.77	**
•	•	•		18	77.8	NS	5.54	NS
•	•		•	19	79.0	NS	5.34	NS
•		•	•	23	78.3	NS	4.04	NS
	•	•	•	51	80.4	*	5.26	*
•	•	•	•	13	76.9	NS	5.61	NS
ALL SITES				338	65.7	-	2.61	-

GROUP B. NEGATIVE ACCIDENT INDICATORS

LOW SFC	NOT A WET-ROAD ACCIDENT PROBLEM	NOT A WET-ROAD SKIDDING PROBLEM	NOT A WET-ROAD SHUNT PROBLEM	NO. OF SITES	SUCCESS RATE		REDPM	
					%	signif.	mean	signif.
•				80	68.8	NS	3.21	NS
	•			76	67.1	NS	2.50	NS
		•		213	60.1	**	1.66	**
			•	176	62.5	NS	2.10	NS
•	•			23	65.2	NS	3.42	NS
•		•		48	62.5	NS	2.32	NS
•			•	40	62.5	NS	2.34	NS
	•	•		69	63.8	NS	1.90	NS
	•		•	61	62.3	NS	1.59	NS
		•	•	133	60.9	NS	1.73	NS
•	•	•		20	60.0	NS	2.54	NS
•	•		•	16	56.2	NS	1.16	NS
•		•	•	31	58.1	NS	1.34	NS
	•	•	•	58	60.3	NS	1.33	NS
•	•	•	•	15	53.3	NS	0.59	NS
ALL SITES				338	65.7	-	2.61	-

Note. NS = not significant
* = significant at probability 0.05
** = significant at probability 0.01

TABLE 8.3 B

Comparison of grouped selection parameters

for anti-skid surface treatment sites

(127 light-controlled intersections)

GROUP A. POSITIVE ACCIDENT INDICATORS

LOW SFC	WET-ROAD ACCIDENT PROBLEM	WET-ROAD SKIDDING PROBLEM	WET-ROAD SHUNT PROBLEM	NO. OF SITES	SUCCESS RATE		REDPM	
					%	signif.	mean	signif.
•				30	63.3	NS	1.82	NS
	•			49	69.4	NS	2.58	NS
		•		51	74.5	*	2.42	NS
			•	67	67.2	NS	2.38	NS
•	•			13	69.2	NS	3.12	NS
•		•		15	73.3	NS	1.84	NS
•			•	16	75.0	NS	2.44	NS
	•	•		27	74.1	NS	3.12	NS
	•		•	29	75.9	NS	3.37	NS
		•	•	36	77.8	*	3.18	NS
•	•	•		7	71.4	NS	3.83	NS
•	•		•	8	75.0	NS	3.56	NS
•		•	•	12	75.0	NS	1.99	NS
	•	•	•	19	79.0	NS	4.14	NS
•	•	•	•	5	80.0	NS	5.20	NS
ALL SITES				127	61.4	-	1.62	-

GROUP B. NEGATIVE ACCIDENT INDICATORS

LOW SFC	NOT A WET-ROAD ACCIDENT PROBLEM	NOT A WET-ROAD SKIDDING PROBLEM	NOT A WET-ROAD SHUNT PROBLEM	NO. OF SITES	SUCCESS RATE		REDPM	
					%	signif.	mean	signif.
•				30	63.3	NS	1.82	NS
	•			22	36.4	**	-1.91	NS
		•		76	52.6	*	1.08	NS
			•	60	55.0	NS	0.76	NS
•	•			6	33.3	NS	-2.80	NS
•		•		15	53.3	NS	1.80	NS
•			•	14	50.0	NS	1.11	NS
	•	•		20	30.0	**	-2.50	**
	•		•	18	44.4	NS	-0.27	NS
		•	•	45	51.1	NS	0.81	NS
•	•	•		5	20.0	*	-3.94	NS
•	•		•	6	33.3	NS	-2.80	NS
•		•	•	11	45.5	NS	1.08	NS
	•	•	•	16	37.5	*	-0.79	NS
•	•	•	•	5	20.0	*	-3.94	NS
ALL SITES				127	61.4	-	1.62	-

Note. NS = not significant
* = significant at probability 0.05
** = significant at probability 0.01

TABLE 8.3 C

Comparison of grouped selection parameters

for anti-skid surface treatment sites

(211 uncontrolled pedestrian crossing sites)

GROUP A. POSITIVE ACCIDENT INDICATORS

LOW SFC	WET-ROAD ACCIDENT PROBLEM	WET-ROAD SKIDDING PROBLEM	WET-ROAD SHUNT PROBLEM	NO. OF SITES	SUCCESS RATE		REDPM	
					%	signif.	mean	signif.
•				50	72.0	NS	4.04	NS
	•			75	76.0	NS	5.31	**
		•		74	74.3	NS	5.49	**
			•	95	69.5	NS	3.73	NS
•	•			12	75.0	NS	4.77	NS
•		•		17	82.4	NS	6.90	NS
•			•	24	75.0	NS	5.17	NS
	•	•		47	74.5	NS	5.73	*
	•		•	47	76.6	NS	5.49	*
		•	•	46	78.3	NS	6.02	*
•	•	•		9	77.8	NS	7.03	NS
•	•		•	8	75.0	NS	6.34	NS
•		•	•	11	81.8	NS	6.28	NS
	•	•	•	31	77.4	NS	5.71	NS
•	•	•	•	6	66.7	NS	6.21	NS
ALL SITES				211	67.8	-	3.21	-

GROUP B. NEGATIVE ACCIDENT INDICATORS

LOW SFC	NOT A WET-ROAD ACCIDENT PROBLEM	NOT A WET-ROAD SKIDDING PROBLEM	NOT A WET-ROAD SHUNT PROBLEM	NO. OF SITES	SUCCESS RATE		REDPM	
					%	signif.	mean	signif.
•				50	72.0	NS	4.04	NS
	•			49	63.3	NS	0.79	*
		•		137	64.2	**	1.98	**
			•	116	66.4	NS	2.79	NS
•	•			11	45.4	NS	-2.31	NS
•		•		33	66.7	NS	2.56	NS
•			•	26	69.2	NS	2.99	NS
	•	•		45	60.0	NS	0.21	**
	•		•	42	61.9	NS	0.65	*
		•	•	88	65.9	NS	2.20	NS
•	•	•		10	40.0	NS	-1.24	NS
•	•		•	10	50.0	NS	0.33	NS
•		•	•	20	65.0	NS	1.48	NS
	•	•	•	39	59.0	NS	0.19	*
•	•	•	•	9	44.4	NS	-0.73	NS
ALL SITES				211	67.8	-	3.21	-

Note. NS = not significant
* = significant at probability 0.05
** = significant at probability 0.01

Examination of the combinations of negative accident indicators (group B) shows that where there is no evidence of a wet-road, wet-road skidding or wet-road shunt accident problem the success rate is lower than average. When each set of negative accident indicators is compared with the equivalent set of positive indicators (group A) it is found that in every case the REDPM values are substantially lower in group B. It should be noted, however, that for all of the group B combinations the mean value of REDPM is in excess of the value of 0.38 which is the criterion for justifying treatment on economic grounds. It cannot, therefore, be concluded that treatment should be withheld from sites at which the SFC is low but where there is no evidence of a specific wet-road accident problem. Nevertheless, it is clear that treatment of such sites would be less cost-effective and for that reason they should be assigned lower priority for treatment.

From examination of Figures 8.3B and 8.3C, where light-controlled junctions and pedestrian crossings are considered separately, the following points emerge:

1. In general, each of the positive accident indicators is a better selection parameter than low-SFC.

2. Success rate and cost-effectiveness increase as more of the positive accident indicators are added to the set of selection parameters. There is, of course, a consequential reduction in number of sites selected as the number of parameters is increased. This is not a disadvantage when funds are available for treatment of only a limited number of sites.

3. Introducing one or more positive accident indicators into the set of selection parameters in addition to low-SFC increases the success rate.

4. Introducing low-SFC in addition to accident parameters does not substantially improve the success rate.

5. At pedestrian crossings the success rate is higher and the treatment is more cost-effective than at light-controlled junctions.

6. Treatment is unlikely to be cost-effective at light-controlled intersections where there is no evidence that the wet-road accident rate is above average.

7. Priority for treatment should be given to sites where skidding accidents have been reported or where there is evidence of two or more associated accident problems.

The overall conclusion is that in the context of a network where the general level of skid resistance is low (in this instance the mean SFC at the experimental sites was 0.35 with only 3% in excess of 0.50) and the proposed treatment gives a substantial increase in SFC then low-SFC is not an important criterion for the selection of sites to be treated. Sites with low SFC should be given high priority for treatment only if there is evidence of an associated accident problem.

CHAPTER 9

ECONOMIC JUSTIFICATION FOR SKID RESISTANCE IMPROVEMENTS

9.1 INTRODUCTION

The social desirability of improving skid resistance in order to reduce accident rates is unquestionable but, since substantial expenditure is involved, it is necessary to consider the economic justification. In the present climate of severe constraints on local government spending it is essential that the most effective use is made of the funds that are available for road improvements and maintenance and that methods of assessment and selection are capable of realistically demonstrating the returns being foregone by failure to increase funding. At a primary level any additional expenditure on skid resistance improvements is justified in economic terms only if it can be shown that there will be a positive net return on the investment, i.e. the benefits are greater than the costs involved. At a secondary level it can only be justified if the rate of return produced is at least equal to that which would be derived from other proposed safety measures within a predetermined budget. There are, of course, many competing claims on the limited funds available to a local authority. Road improvements and maintenance are fairly low on the list of political priorities and tend to be subjected to closer financial scrutiny than other areas of public expenditure.

In making an economic assessment of an individual scheme it is necessary to estimate the costs and benefits in each year throughout the life of the scheme and to calculate the net value. Thus, in year n the net value is

$$(B_n - C_n)$$

where B_n = total benefits in year n

C_n = total costs in year n

With most schemes the engineering costs are incurred mainly at the outset (year 0) but the benefits are spread out over the life of the scheme. In order to compare costs and benefits on the same basis the net benefit for year n is discounted to give its present value by multiplying by

$$1/(1 + r)^n$$

where r is the discount rate expressed as a fraction. A discount rate of 7% is currently used by the DTp (103) for the assessment of highway engineering projects.

The overall net present value (NPV) of a scheme with an anticipated life of N years is given by

$$NPV = \sum_{0}^{N}(B_n - C_n)/(1 + r)^n.$$

The scheme is economically viable if NPV is positive, i.e. if the present value of the benefits (PVB) is greater than the present value of the costs (PVC).

Since financial budgets are always limited it is rarely possible to implement all proposed schemes having a positive NPV; to make the most effective use of the available funds it is necessary to rank schemes. Simply ranking on the basis of NPV tends to favour the larger, possibly less cost-effective schemes. A better ranking parameter is the present value/cost ratio (NPV/PVC).

In the field of low-cost accident remedial measures first-year rate of return (B_0/C_0) is commonly used as a selection and performance parameter. In the I.H.E. publication "Guidelines for Accident Reduction and Prevention in Highway Engineering" (3) it is recommended that the target first-year rate of return should be a minimum of 50% for single sites and 40% for sites included in a mass action plan (such as a skid resistance improvement programme). The GLC Road Safety Section selection criterion for engineering measures at accident black spots is a first-year rate of return of at least 100% (104).

The principal benefit arising from an improvement in skid resistance is a reduction in the number of accidents and a monetary value may be assigned to each accident prevented. Possible subsidiary benefits, which are very difficult to quantify, might include a reduction in spray from vehicle tyres in wet weather and an improvement in uniformity of luminance at night. If the increase in skid resistance involves laying a new wearing course there might be some structural enhancement and an improvement in riding quality, the financial benefit of which should also be incorporated.

Apart from the initial capital expenditure (and possible maintenance costs) additional costs might arise from traffic delays while the work is in progress, accidents directly attributable to the maintenance operations themselves, shattering of vehicle windscreens by flying chippings during the early life of the treatment, increased tyre wear, increased rolling resistance (leading to higher fuel consumption) and increased tyre/road noise.

Cost of road accidents

Dawson (15,105) has produced estimates of the measurable costs to the community of road accidents in Great Britain. He took into account the value of the loss of output of the casualties, costs of medical treatment, damage to vehicles and other property, and administrative costs. He also added a notional amount, subsequently increased on the recommendation of the Leitch Report (106), for the cost of the suffering and grief involved. From insurance company records he was able to estimate the number of damage-only accidents. He found that the average number of damage-only accidents per injury accident was 6.4 in urban areas, 4.6 in rural areas and 6.0 overall. It is reasonable to assume that measures taken to reduce the incidence of injury accidents will also reduce damage-only accidents by a similar proportion and it is customary to include the value of the damage-only accidents in any estimates of savings in accident costs.

Dawson's estimates are updated annually by the DTp (e.g. 107). Table 9.1 gives a breakdown of costs by severity (mid-1983 prices) and Table 9.2 shows average costs per accident by severity and class of road (i.e. urban, rural or motorway). It will be seen that the average cost per urban injury accident (including an allowance for damage-only accidents) is £8,260. On rural roads and motorways the average costs are higher (£15,030 and £15,250 respectively), reflecting the fact that injuries arising from accidents on these roads tend to be more severe, there are more casualties per accident than on urban roads (1) and the costs (per accident) of providing emergency services are higher.

TABLE 9.1

Average accident costs by severity (1983) £'s

TYPE OF ACCIDENT	LOST OUTPUT	MEDICAL & AMBULANCE	POLICE & ADMIN.	DAMAGE TO PROPERTY	PAIN, GRIEF & SUFFERING	TOTAL
Fatal	118,130	880	280	1,530	46,360	167,160
Serious	1,590	1,670	220	1,240	4,740	9,460
Slight	20	80	170	870	100	1,240
All injury	2,850	490	180	970	2,204	6,700
Damage only	-	-	60	460	-	520

TABLE 9.2

Average accident costs by class of road (1983) £'s

TYPE OF ACCIDENT	URBAN ROADS	RURAL ROADS	MOTORWAYS	ALL ROADS
Fatal	158,960	176,070	193,770	167,160
Serious	8,640	11,360	11,310	9,460
Slight	1,080	1,890	2,070	1,240
All injury	5,100	12,250	12,050	6,700
Damage only	500	600	710	520
Average cost per injury accident (including allowance for damage-only accidents)	8,260	15,030	15,250	9,790

9.2 ATTAINMENT OF MAXIMUM SFC THROUGHOUT URBAN CLASSIFIED ROAD NETWORK

In Chapter 8 it was estimated that the number of wet-road accidents could be reduced by 34.9% by the application of a resin/bauxite surface dressing to give the maximum practicable SFC. In this section the costs associated with the treatment are compared with the benefits to establish whether the required expenditure is justified.

(i) Treatment Costs

In London in 1983 the price of the resin/bauxite treatment was approximately £7.25/m². The price was based on a contract for a large overall area (a guaranteed minimum of 50,000m² in 12 months) involving relatively small average areas per site (500 - 1,500m²) with the contractor being restricted to night-time or weekend working to minimise disruption to traffic. Prices outside the GLC area have tended to be higher because the resin/bauxite treatment programmes of other authorities have been on a smaller scale. A major extension of the programme would enable the contractors to reduce overheads and improve productivity. This would reduce unit costs but for the present economic assessment the above figure will be used.

On Principal roads in London the average road width is 10 metres. Therefore, the average cost of treating one kilometre of road is £72,500. The full treatment cost is incurred at the outset; maintenance costs thereafter are minimal. The mean service life, based on present experience, is about 10 years.

(ii) Other Costs

A. Traffic Delays. Resurfacing operations can often involve substantial delays (and consequently extra costs) to road users, especially when it is necessary to remove the existing wearing course or to raise threshold levels (kerbs, footways, gulley gratings, etc.) to accommodate the additional thickness. However, in the case of the resin/bauxite treatment the applied layer is very thin (about 3mm) and no auxiliary work is normally required. Experience has shown that providing the work is planned carefully and carried out at off-peak times the delay costs to road users are negligible.

B. Windscreen Breakage. Damage to vehicle windscreens caused by loose chippings thrown up from the road by vehicle tyres is a considerable nuisance associated with conventional surface dressings and can be a safety hazard. With the resin/bauxite treatment there are always some loose chippings during the first few weeks after application but they are very much smaller than chippings used in conventional surface dressing (only 1-3mm) and so are less of a hazard. There have been no reports in London of any windscreen (or other) damage caused by flying bauxite chippings.

C. Rolling Resistance. As discussed in Chapter 4, an increase in macrotexture can increase rolling resistance (and hence fuel consumption) but the texture depth of the resin/bauxite treatment is only moderately high (about 1mm) and in many instances will be no higher than on the surface being covered.

D. Tyre/Road Noise. The level of noise generated at the tyre/road interface on the resin/bauxite surface is not perceptibly different from that on typical conventional surfaces.

E. Tyre Wear. The rate of wear of vehicle tyres is undoubtedly greater on the resin/bauxite surface because of the high microtexture of the bauxite particles and this could be a significant additional cost to the road user. Some preliminary work has been done at Queen Mary College (108) on comparing rates of tyre wear on bauxite and conventional roadstones but it is not yet possible to produce a reliable estimate of the additional costs.

(iii) Accident Savings

The estimated potential saving in accidents on classified roads in London was 2,752 per annum. The length of classified road is 3,120 km. Thus, the predicted saving is 0.882 accidents/km/annum.

Nationally, the estimated potential saving was 9,652 accidents on the 31,700 km of urban classified road, an average of 0.304 accidents/km/annum.

Taking the average accident cost as £8,260, with a 7% discount rate, the present value of the accident savings during the 10-year average treatment life is:-

£50,786/km for London

£17,504/km for urban classified roads generally.

(iv) Other Benefits

There are no significant additional benefits arising from the application of the resin/bauxite surface dressing. Because it is very thin it has no structural value and gives no improvement in riding quality.

(v) Present Net Value

Since the present value of the benefits is less than the costs involved (both for London and Great Britain generally) the present net value is negative and it must, therefore, be concluded that there is no economic justification for the unselective treatment of all urban classified roads with resin/bauxite surface dressing.

Although it is technically possible to maintain a very high skid resistance on all urban roads by the use of the resin/bauxite treatment there are various reasons why such a policy would not be desirable.

1. As shown above, the cost of the treatment would be greater than the likely saving in accident costs.

2. As was shown in earlier chapters, there are many sections of road where, because braking or violent manoeuvring rarely occur, the level of frictional demand is very low. A low level of skid resistance is acceptable in such areas and it would be a waste of resources to lay an expensive anti-skid surface.

3. Similarly, there are many sections of road where the accident rate is very low. Expenditure on improving the skid resistance at such locations would be wasted because the potential saving in accident costs would be correspondingly small.

4. It is known that the rate of tyre wear is substantially higher on resin/bauxite surfaces than on conventional surfaces (although the difference has not yet been quantified precisely). It would be economically unjust to impose additional tyre replacement costs on vehicle owners by using the resin/bauxite treatment at locations where high skid resistance is not required. It is possible that the additional tyre wear costs could nullify the saving in accident costs.

5. At present there is only a limited supply of calcined bauxite of suitable quality and if widespread use of the resin/bauxite treatment were to be undertaken then demand would soon exceed supply. Even before this situation arose the increase in demand would lead to higher prices and this would increase the cost per accident saved.

6. It is possible that if the skid resistance of the network were to be uniformly high then drivers would tend to adjust their driving technique in such a way as to diminish the expected reduction in accidents (the risk compensation theory).

7. The required resources could be put to better use on other accident-saving measures showing higher rates of return than the additional schemes that would be brought into an enlarged programme.

It has been clearly demonstrated that there is justification for improving urban skid resistance levels but the resin/bauxite treatment must be used selectively and consideration must be given to whether the use of other materials might be more cost-effective.

9.3 MAXIMUM SFC AT SELECTED LOCATIONS

In the preceding section it was shown that the use of resin/bauxite surface dressing on the whole of the urban classified road network could not be justified because the treatment costs would exceed the likely saving in accident costs. However, if used at carefully-selected locations the treatment can be highly cost-effective.

Consider the 338 experimental sites described in Chapter 7. Of these, 127 were light-controlled junctions and 211 were at uncontrolled pedestrian crossings. At the average light-controlled junction site an area of 1,000m² was treated at a cost of £7,250. The net reduction in accidents (after allowing for changes at control sites) was 0.539 per annum. Assuming a life of 10 years, an average accident cost of £8,260 and a discount rate of 7%, the present value of the accident savings is £31,036. Thus, the net present value is £23,786 which represents an overall net return of 328% on the expenditure or an average annual rate of return of 32.8%.

The treatment was even more cost-effective at the pedestrian crossing sites. At the average site an area of 550m² was treated, costing £3,990 and producing a net reduction of 0.588 accidents per annum. The present value of the accident savings is £33,857, giving a net present value of £29,867 which is 749% of the treatment cost or an average annual rate of return of 74.9%.

Based on the same assumptions as made above, and ignoring additional tyre wear costs, treatment is economically worthwhile at any site where the likely saving in accidents is at least 0.126/annum/1000m² treated.

If the network is divided into equal lengths of (say) 100 metres then an assessment can be made of the accident saving potential within each section. The cost of treating a hundred-metre section (assuming the average road width is 10 metres and the treatment extends across the full width of the road) is £7,250. Thus, treatment of a section is justified if the predicted saving in accidents is at least 0.126/annum.

As was shown in Chapters 7 and 8 it is not easy to reliably predict the accident savings at a particular location but a first-order approximation may be made by taking the predicted saving as 34.9% of the wet-road accident total at nodes and 26.8% within links. Using three-year accident totals (and assuming a 10-year life) treatment of a 100-metre section is justified if the number of wet-road accidents in the three-year period exceeds one.

The length of the Non-Trunk portion of the classified road network in London is 2,899 km (1416 km Principal and 1,463 Non-Principal) of which approximately 500 km is in the immediate vicinity of nodes (the intersection of classified roads) and the remaining 2,400 km form the links (the lengths of road between nodes). A representative sample of 429 one-hundred metre sections of road was drawn from all 32 boroughs and wet-road accident numbers were obtained for each section in the three-year period 1979-81 (see Table 9.3).

TABLE 9.3

Wet-road accident totals in 100-metre sections of road within links (1979-81)

number of wet-road accidents in 3 years	number of sections	
	Principal	Non-Principal
0	114	141
1	58	45
2	29	14
3	10	4
4	8	-
5	2	-
6	2	-
7	2	-
8 or more	-	-
Total	225	204

It will be seen that there are 2 or more accidents, indicating that treatment is justified, at 53 (23.6%) of the Principal sections and 18 (8.8%) of the Non-Principal sections. Equally noteworthy is the fact that there are no wet-road accidents and therefore no potential for accident reduction at 51% of the Principal sections and 69% of the Non-Principal sections.

Treatment of the 53 Principal sections would produce a predicted saving of 13.94 accidents per annum (i.e. a 26.8% reduction at the treated sites, constituting 19.5% of the annual wet-road total at all 225 Principal sections - the sections selected for treatment plus the remainder) The present value of the savings that would accrue over the 10-year life of the treatment is £802,700 and the treatment cost is £384,250. Thus the overall discounted net return is 109% (10.9% net per annum).

Treatment of the 18 Non-Principal sections would produce a predicted reduction of 3.22 accidents per annum (11.9% of the annual total at the 204 Non-Principal sections) and would give a net return of 42% (4.2% net per annum).

Three-year wet-road accident totals at a representative sample of 522 nodes are shown in Table 9.4.

TABLE 9.4

Wet-road accident totals at nodes (1979-81)

number of wet-road accidents in 3 yrs.	nodes on Principal roads		nodes on Non-Principal roads
	conventional surfacing	anti-skid surface	
0	40	12	95
1	43	15	59
2	41	11	32
3	31	9	17
4	22	9	9
5	12	8	9
6	11	7	4
7	4	4	-
8	5	1	1
9	2	2	-
10	-	3	-
11	1	1	-
12	-	1	-
13	-	1	-
14 or more	-	-	-
Total	212	84	226

The area of road involved at a node depends on the number of arms at the junction and the geometric layout. GLC experience, based on detailed study of individual accidents, is that treatment is usually necessary only on the approaches to,and the centre of,the junction. Whether or not the minor arms are treated depends upon the accident pattern. The average treatment area for junctions on GLC roads is 1,000m^2 and so, in the present context, the justification criterion is the same as for the 100-metre link sections, i.e. a minimum predicted saving of 0.126 accidents/annum (which is indicated by a wet-road accident total of more than one in a three-year period). It will be seen that of the 212 conventionally-surfaced Principal road nodes 129 (60.8%) have a three-year wet-road total of two or more. Seventy-two (31.9%) of the Non-Principal sections have two or more wet-road accidents. Eighty-four Principal nodes have already been treated with resin/bauxite. It is assumed that, since treatment of Non-Principal roads is extremely rare, all the Non-Principal nodes are conventionally surfaced. Thus, 16.1% of Non-Trunk nodes in London have been treated and there is justification for the treatment of a further 38.5%.

9.4 VALUE OF 0.10 INCREASE IN SFC

There are various ways of achieving a moderate increase in SFC and it is of considerable interest to know what the benefit would be in terms of savings in accident costs. In Chapter 8 it was estimated that an increase of 0.10 in SFC would reduce wet-road accidents on classified roads in London by 1,186 annually which is equivalent to 0.380/km/annum. At 1983 prices this is a saving in accident costs of £3,140/km/annum. On urban classified roads generally the estimated reduction is 0.132 accidents/km/annum, with a value of £1,090/km/annum.

The above estimate can be used to determine whether the additional materials costs that might be involved are warranted. For example, in London, compared with a hot-rolled asphalt wearing course of the same thickness, a Delugrip wearing course costs approximately 80p/m^2 more (£8,000 per km more, assuming an average road width of 10 metres). When its design, manufacture and application are properly controlled, it has been found to give SFC values approximately 0.10 higher than hot-rolled asphalt with chippings of similar PSV. In principle, the service life should be the same as for hot-rolled asphalt (viz. about 20 years) though this is not yet proven. The present value of the accident savings over 20 years is £35,600 per km on London roads. Thus, providing the expected life is achieved, the additional cost of using Delugrip in routine resurfacing is amply justified.

9.5 USE OF HIGHER PSV ROADSTONE

Probably the simplest way of improving skid resistance levels is to use roadstone of higher PSV when a road is to be routinely resurfaced. Szatkowski and Hosking (8) found that an increase of one unit in PSV produced an increase of 0.01 in SFC. The results of the survey in the present study (see Chapter 4) suggest that on urban roads the increase in SFC is approximately 0.008 per unit increase in PSV. On the basis of the latter estimate, an increase in PSV of 12 units would increase SFC by 0.10 and (as shown in Section 9.4) this would give a predicted saving in accident costs of £3,140/km/annum (1983 prices) on classified roads in London and £1,090/km/annum on urban classified roads generally.

The PSV of roadstones on most urban main roads is typically in the range 50 - 60. For some years the GLC policy has been to use higher PSV stones (PSV range 57 - 72) and this has also led to increased use of these stones on Borough roads. The average PSV on classified roads is about 60 in London (steadily increasing as more roads are resurfaced using higher PSV stone) and 55 elsewhere. Stones with higher PSV attract higher prices and their use elsewhere is restricted mainly to the few locations where the risk of skidding is judged to be exceptionally high. The complex nature of the pricing arrangements between aggregate suppliers and contractors makes it difficult to establish average roadstone prices but the results of informal enquiries suggest that in 1983 the ex-quarry prices of uncoated 20 mm chippings were approximately as shown below.

PSV	£/tonne
50	5
55	7
60	10
65	14
70	21
72	25

The average rate of spread of 20 mm chippings in hot-rolled asphalt on urban roads is approximately 10 kg/m². An increase in PSV from 55 to 67 would raise the price by £9-50/tonne (or £950 per km of road, assuming a road width of 10 metres) which is equivalent to only 9.5p/m². An increase in PSV from 60 to 72 would cost 15p/m² more (or £1,500 per km) and would produce estimated accident savings of £3,140 annually. Thus, the extra cost would be recovered within one year. Assuming a 20-year life for the surfacing, the present value of the accident savings is £35,600 per km, which is an overall net return of

2,270% on the additional expenditure. On urban classified roads generally, the equivalent net return is 1,200%.

It is clear that the use of higher PSV stones would be highly cost-effective. Moreover, the additional capital expenditure involved would be relatively small. The basic cost of supplying and laying a hot-rolled asphalt wearing course in London is £4/m^2 (see Sect. 4.5.2) with chippings of PSV 60. The additional cost of 15p/m^2 for chippings of PSV 72 would represent an increase of less than 4%.

The view is sometimes expressed that there is a need to conserve stocks of high-PSV stones and that they should be used only where absolutely necessary. Hawkes and Hosking (see Sect 4.3) have shown that there are substantial reserves of high-PSV stone in Great Britain. Fears about resource depletion are groundless and should not be an inhibiting factor. Greater demand for the higher PSV stones would probably increase price differentials but the benefits in accident savings resulting from their use are so great that this would not alter the general conclusion that they are highly cost-effective.

9.6 COMPLIANCE WITH LR 510 (AND ALTERNATIVE SFC IMPROVEMENT OPTIONS)

9.6.1 Introduction

In the system of standards proposed in LR510 by Salt and Szatkowski (discussed in Chapter 5) the minimum SFC required at an individual location is defined on the basis of the Risk Rating for the site. There is a range of risk ratings (and corresponding target SFC values) for various categories of site (see Table 5.9). Mention has been made in earlier chapters of the fact that SFC levels on urban main roads are generally below the levels recommended in LR510, particularly at high-stress locations (approaches to traffic signals, pedestrian crossings, etc.). In this section the Principal roads in a typical London borough (Borough B) are examined; firstly to assess the extent to which compliance with LR510 is achieved, secondly to establish whether full compliance is feasible and finally to determine whether compliance would be cost-effective. It is convenient to consider nodes and links separately.

9.6.2. Nodes

Option A - Compliance with LR510

Each of the 130 nodes in the borough was inspected and a subjectively-assessed, risk rating in accordance with LR510 assigned. All but 5 of the nodes were found to be in either category A1 (very difficult), with risk rating to be selected from within the range 6 to 10, or category A2 (difficult), with risk rating 4 to 8. Estimates of mean summer SFC (based on the 1979 SCRIM survey) were obtained for each site for comparison with the required SFC values corresponding to the risk rating. Inspection of the road surface revealed that 59 of the sites had been treated with resin/bauxite and the remaining 71 were surfaced with conventional hot-rolled asphalt. Details of the sites (including accident totals for 1977-81) are given in Appendix F.

Compliance with LR510 was achieved at only one of the conventionally-surfaced sites. The SFC at 39 (66%) of the resin/bauxite sites was equal to, or in excess, of the required value.

The SFC at the conventionally-surfaced sites could be improved by replacing the wearing course using chippings with a higher PSV. Szatkowski and Hosking (see Sect.4.4) found that for rolling traffic on rural roads the SFC could be predicted from the equation

$$S = 2.4 \times 10^{-2} - 6.63\ t\ 10^{-5} + p \times 10^{-2} \qquad \underline{A}$$

where S = equilibrium mean summer SFC

t = commercial vehicles per lane per day (cvd)

p = PSV

Hence the PSV required to achieve the target SFC is given by

$$p = S \times 10^{2} - 2.4 + 6.63\ t\ 10^{-3} \qquad \underline{C}$$

Hosking and Tubey (42) showed that at locations where traffic was braking and/or turning a PSV about 5 units higher was required. Thus, at high-stress locations

$$p = S \times 10^{2} + 2.6 + 6.63\ t\ 10^{-3} \qquad \underline{D}$$

In Chapter 4 it was shown that SFC levels on urban main roads are lower than indicated by Equation A but for the present it will be assumed that equations A, C and D are valid for urban roads. The nodes are all at braking/turning locations and so the use of Equation D is appropriate. Estimates of commercial vehicle flow in the most heavily-trafficked wheel track at each site were obtained and were used to calculate the PSV required to achieve the target SFC (see Table 1, Appendix F).

The highest PSV for durable roadstone available in quantity in sizes suitable for coated chippings in hot-rolled asphalt is 72. The PSV requirement at 39 (56%) of the non-compliant conventionally-surfaced nodes is in excess of that value. Many of the more heavily-trafficked nodes had already been treated with anti-skid surfacing. If the PSV requirement at all 130 nodes is considered it is found that 78 (60%) require a PSV above 72. It is interesting to note that, in theory, compliance could have been achieved with conventional hot-rolled asphalt at 19 of the sites at which resin/bauxite had been used, though that is on the assumption that Equations A, C and D are valid. It was shown in Chapter 4 that SFC levels on urban main roads are lower than indicated by these equations, possibly due in part to lower rates of spread of chippings but probably also because of a more severe polishing action per commercial vehicle. This means that PSV values higher than indicated by equations C and D would be necessary in practice and compliance would be feasible at a smaller proportion of sites. Thus, it is reasonable to conclude that compliance with the minimum SFC values required in LR510 is feasible, using conventional hot-rolled asphalt, at less than 40% of category A1 and A2 sites in Borough B.

Despite the fact that the resin/bauxite treatment gives the highest practicably-attainable SFC about one-third of the treated sites were below the target level. Examination of a number of treated sites where SFC values were relatively low revealed that in several cases the surface was badly worn and was nearing the end of its life. However, most of the non-compliant resin/bauxite sites were in sound condition. This suggests that the higher target SFC values (0.70, 0.75) in LR510 are unrealistic. It is possible that they were actually intended to represent the values that would be obtained with the resin/bauxite. These values are, in fact, typical of the SFC on resin/bauxite surfaces at around the time that LR510 was published (1973) as measured with the SCRIM test vehicle (92). It was not until several years later that it was realised that SCRIM gave higher values than the equipment previously in use and that the recorded values needed to be adjusted (see Sect.3.4). There would, therefore, appear to be a case for reducing the category A1 target values on the grounds that they are not achievable and are probably higher than was originally intended.

The cost of achieving compliance at each of the conventionally-surfaced non-compliant sites was calculated assuming (initially) that :

1. The relationship between SFC, PSV and traffic flow defined in Equation D is valid for urban roads (but see later).

2. Where compliance can be achieved by using a higher-PSV stone the SFC improvement is not implemented until the wearing course is due for replacement for structural reasons. Thus, the additional cost is confined to the extra cost of the higher-quality chippings.

3. The standard wearing course would have had chippings of PSV 60. The additional cost per site of the higher-PSV chippings is calculated from the ex-quarry prices given in the previous section, interpolating where necessary.

4. The rate of spread of chippings is 11.5 kg/m^2 on both the standard surface and the high-PSV surface.

Table 9.5, based on the chipping prices given earlier, shows the unit cost for chippings of different PSV and the additional costs (compared with a PSV datum of 60) if higher PSV stone is used.

TABLE 9.5

Unit costs of chippings in relation to PSV

PSV	£/tonne	p/kg	p/m^2	£/1000m^2	additional cost relative to PSV 60 (p/m^2)
60	10.0	1.00	11.5	115	0
61	10.6	1.06	12.2	122	7
62	11.4	1.14	13.1	131	16
63	12.2	1.22	14.0	140	25
64	13.1	1.31	15.1	151	36
65	14.0	1.40	16.1	161	46
66	15.3	1.53	17.6	176	61
67	16.5	1.65	19.0	190	75
68	18.0	1.80	20.7	207	92
69	19.6	1.96	22.5	225	110
70	21.2	2.12	24.4	244	129
71	23.0	2.30	26.5	265	150
72	25.0	2.50	28.8	288	173

At the 31 non-compliant conventionally-surfaced sites where it is possible to achieve compliance with hot-rolled asphalt the additional cost is £2150 (or only £69 per site on average). At the remaining 39 sites compliance would cost considerably more. It might be possible to achieve compliance at some of the sites using one of the alternative processes described in Chapter 4 (e.g. pervious macadam friction course or Delugrip) but at most sites it is likely that the resin/bauxite treatment would be necessary. Hot-rolled asphalt wearing course has an average life of 20 years whereas the life of resin/bauxite is 10-12 years. If the two materials are to be compared on an equal basis allowance must be made for the cost of renewing the resin/bauxite. Assuming that this is done after 10 years the present value of the retreatment cost is £3,680 per 1000m^2, giving a 20-year treatment cost of £10,930 per site at present values. The total cost of the resin/bauxite treatment at the 39 sites is £426,300. Thus the overall cost of achieving compliance at the 70 non-complying sites which are at present conventionally surfaced is £428,450.

The predicted accident savings over 20 years resulting from the increase in SFC at the 70 sites was calculated on the assumption that wet-road accidents would be reduced by 1.16% per 0.01 increase in SFC and that at all sites (including those treated with resin/bauxite) the precise target SFC would be achieved. The predicted reduction in accidents is 512 over 20 years (108 at sites where hot-rolled asphalt is used and 404 at resin/bauxite sites) which represents a reduction of 32.0% at these sites.

The present value of the accidents saved over 20 years is £2,406,000 which is 5.6 times the cost of improving the SFC, giving a net annual return of 23.0%. Thus, on the basis of the assumptions listed above, the expenditure required to achieve compliance with LR510 at nodes is justified by the saving in accident costs.

The compliance costs and benefits are shown in Table 9.6. It will be seen that at sites where compliance can be achieved using hot-rolled asphalt the net annual economic return is very much greater than at sites where resin/bauxite is used (1,166% compared with 23%). The cost per accident saved is only £20 at the hot-rolled asphalt sites compared with £1,054 at the resin/bauxite sites.

TABLE 9.6

Costs and benefits associated with improving SFC at 70 conventionally-surfaced nodes in Borough B which do not comply with LR510

OPTION A ..... Compliance with LR510 using
HRA with PSV as required (up to PSV 72)
- resin/bauxite at remaining sites

surface type	HRA	resin/bauxite	all sites
PSV	as required	-	-
No. of sites	31	39	70
Overall cost of treatment (present value)	£2,150	£426,300	£428,450
Accident reduction (20 years)	107.6	404.4	512.0
Accident reduction as % of wet-road accidents	24.7	34.9	32.1
Saving in accident costs (present value)	£503,700	£1,893,000	£2,396,700
Net annual economic return (%)	1166.0	17.2	23.0
Cost of preventing one accident	£20	£1,054	£837

Note: See comments in text regarding validity of this assessment

As noted earlier, the resin/bauxite treatment gives a mean SFC value of 0.65 and so compliance cannot be assured at sites where the required minimum is in excess of this value. Assuming that all the resin/bauxite sites would have SFC 0.65, rather than the precise target value, gives (coincidentally) the same estimated accident reduction at this group of sites . From this point it will be assumed that the SFC of each of the resin/bauxite sites is 0.65.

It must be accepted that compliance with LR510 is impracticable at all high-risk and/or heavily-trafficked nodes with conventional surfacings and the very large capital expenditure entailed in the use of resin/bauxite makes it unlikely that many highway authorities would make extensive use of this treatment to achieve compliance at these locations. It is, therefore, necessary to consider policies other than the attainment of full compliance with LR510.

OPTION B. - Compliance with LR510 where possible, using hot-rolled asphalt with chippings of PSV as required (up to PSV 72).
- At sites where PSV requirement is > 72 resin/bauxite used where economically justifiable (i.e. at sites with 2 or more wet-road accidents in five years).
- Hot-rolled asphalt with PSV 72 at remaining sites.

OPTION C. - No resin/bauxite
- PSV as required (up to 72)
- PSV 72 at remaining sites

OPTION D. - No resin/bauxite
- PSV 72 at all sites

OPTION E. - Resin/bauxite at all sites

OPTION F. - No resin/bauxite
- Increase of 0.10 in SFC at all sites

OPTION G. - Resin/bauxite at 20% of sites
- No action at remaining sites

OPTION H. - Resin/bauxite at 20% of sites
- Increase of 0.10 in SFC at remaining sites

The costs and benefits associated with each option are tabulated in Appendix F (Table F.2) and are summarised in Table 9.7 below.

In Option B the resin/bauxite treatment is confined to those sites where the predicted saving in accident costs exceeds the treatment cost (i.e. sites with 2 or more accidents in 5 years) but it is found that the treatment is economically justified at all but 3 of the 39 sites where compliance could not be achieved using hot-rolled asphalt. Thus, there is little change in the overall economic assessment.

In Option C hot-rolled asphalt with chippings of PSV 72 is substituted for the resin/bauxite treatment. This requires an overall expenditure of only £8,900 (compared with £428,450 for Option A). Compliance would be achieved at fewer than 32 of the 70 sites but the policy would be extremely cost-effective, giving a 25.9% reduction in wet-road accidents and a net economic return of 1083% per annum. In Option D hot-rolled asphalt with PSV 72 is used at all 70 sites. This would be slightly more expensive than Option C and would give a greater accident reduction (28.1%). This highlights the fact that if a policy is adopted (as implied in LR510) of selecting the precise PSV required to achieve the target SFC value, rather than using the highest PSV available, then the saving in materials costs would be very small and the opportunity of possible additional accident savings would be foregone. Use of resin/bauxite at all 70 sites (Option E) would produce the maximum accident reduction. It would be very expensive (£765,000) but would, nevertheless, be cost effective, giving a net return of 12.2% per annum.

There is a relatively small difference in predicted wet-road accident reduction between Option E (all resin/bauxite) and Option D (all PSV 72) - 35.3% compared with 28.1%. The mean SFC at the 70 sites is 0.35. It is known that the average SFC obtained with resin/bauxite at high-stress sites is 0.65, an increase of 0.30. From Equation D it is predicted that the average SFC on hot-rolled asphalt with PSV 72 would be 0.60, an increase of 0.25. There is considerable doubt about the latter estimate (and the associated estimates of accident reductions). The average PSV on the existing surfaces at these sites is approximately 60 (see 4.4) and it is extremely unlikely that a 12-unit increase in PSV would give an increase of 0.25 in PSV. A more realistic estimate of the likely effect of using PSV 72 would be an increase of approximately 0.10 in SFC. This is shown as Option F. The wet-road accident reduction is more modest (11.6%) but, since the additional costs involved are low, it would still be extremely cost effective, giving a net annual return of 353%. The doubts about the validity of the earlier predictions relating to PSV 72 extend to the other predictions for hot-rolled asphalt in Options A, B and C. Clearly, compliance with LR510 would be feasible using hot-rolled asphalt at a lower proportion of sites than the 44% (31 sites) indicated by Equation D and Options A to D would be less cost effective than indicated in Tables 9.6, 9.7 and F.2.

There will always be some sites where the highway authority will wish to attain the highest possible SFC in order to achieve maximum reduction in accidents. The number of sites treated with resin/bauxite will depend on the funds available. Treatment of the 20% of sites at which wet-road accident totals are highest (Option G) would reduce wet-road accidents by 295 in 20 years (36.3% of wet-road accidents at the treated sites and 18.5% of the wet-road total at all 70 sites) and would give a net economic return of 40.1% per annum.

A policy of general improvement of SFC by using high-PSV chippings in routine resurfacing, in conjunction with selective treatment of individual sites with resin/bauxite would give a substantial reduction in accidents at a moderate cost. Option H (resin/bauxite at 20% of sites, hot-rolled asphalt with PSV 72 at remainder) would involve additional expenditure of £163,000 and would reduce wet-road accidents by 24.2%, giving a net economic return of 50.4% per annum.

TABLE 9.7

Costs and benefits associated with improving SFC at 70 conventionally-surfaced nodes in Borough B

Option	Expenditure required £	% Reduction in wet-road accidents	Net annual economic return (%)	Cost of saving one accident £
A*	428,000	32.1	23	837
B*	396,000	32.0	25	774
C*	8,900	25.9	1,083	22
D*	12,100	28.1	863	27
E	765,000	35.3	12	1,360
F	12,100	11.6	353	65
G	153,000	18.5	40	519
H	163,000	24.2	50	422

* See comments in text regarding validity of estimates in Options A to D

9.6.3 Links

The survey of 268 one-hundred-metre sections of road within links in Borough B was described in Chapter 6 and the site details (including SFC values and accident numbers) are given in Appendix D. The link sections were assessed on the same basis as the nodes; the only difference being that the rolling traffic condition was assumed and, therefore, Equation C was used for determining the required PSV. A high proportion of the sites were in LR510 category B(ii)(average) with risk ratings and associated required SFC values being generally lower than for the node sites. Nevertheless, only 68 sites (25.4%) had mean SFC values at or above the required level. The mean SFC at the 200 non-complying link sections was 0.36 and the mean target SFC (for compliance with LR510) was 0.47. Thus the average increase required is only 0.11. On the basis of equation C it was calculated that compliance could be achieved at 195 (97.5%) of the non-complying sites with roadstones of PSV up to 72, leaving only 5 sites where resin/bauxite surface dressing might be necessary. Thus, substantial compliance with LR510 is, in principle, feasible using conventional surfacings. There is, of course, some doubt as to whether SFC values achieved on urban roads with a given PSV would be as high as is indicated by Equation C. Using the regression equation developed in Chapter 4 for link sections (Equation B in Sect.4.4.4) it is found that compliance is feasible using hot-rolled asphalt at 135 (67.5%) of the non-compliant sites. Equation B relates to the levels of SFC currently being achieved on roads in London. As noted in 4.4, it is probable that a higher SFC could be achieved with a given PSV by increasing rates of spread of chippings. Thus, the proportion of link sections at which compliance is feasible is somewhere between 67.5% and 97.5% of the non-compliant link sections, and hence at 75.7% to 98.1% of all link sections.

It is clear that substantial compliance can be achieved on links, using hot-rolled asphalt with chippings of higher PSV. It is estimated that achieving compliance would reduce the number of wet-road accidents at the 200 currently non-compliant sections by 360 in 20 years (a reduction of 15.4%). The present value of the accident savings would be £1,687,000. On the basis of Equation C, the requirement is for 195 sites to be resurfaced with chippings of appropriate PSV and 5 sites to be treated with resin/bauxite. The cost would be £56,700, giving a net annual economic return of 143.8% per annum. On the basis of Equation B the number of sites requiring resin/bauxite increases to 65, the overall cost would be £734,000 giving a net return of 10.1% per annum. Thus full compliance with LR510 would be feasible on links in Borough B and would be cost effective.

Use of hot-rolled asphalt with chippings of PSV 72 on all 200 non-compliant sites would, on the basis of Equation B, give an average increase of 0.13 in SFC and would cost £34,600. This would produce an estimated reduction in wet-road accidents of 361 (15.4%) over 20 years, with a present value of £1,690,000 giving a net annual return of 239%. This policy would, therefore, produce accident savings almost identical to the policy of precise compliance with LR510 and would be more cost efective.

9.6.4 Summary of findings for Borough B.

1. Compliance with LR510 is achievable using hot-rolled asphalt with chippings of appropriate PSV at between 76% and 98% of link sections. Use of treatments such as resin/bauxite surface dressing would be necessary to achieve compliance at the remaining sections.

2. Full compliance at the link sections would be cost-effective and would reduce wet-road accidents at the currently non-compliant sites by an estimated 15.4%.

3. Use of hot-rolled asphalt with chippings of PSV 72 would reduce wet-road accidents by a similar extent and would be much cheaper.

4. At nodes compliance is feasible, using hot-rolled asphalt, at fewer than 40% of sites. Even with resin/bauxite compliance cannot be assured at sites of highest risk (requiring a minimum SFC of 0.70 or 0.75).

5. Use of resin/bauxite at all nodes in Borough B would give substantial compliance and would reduce wet-road accidents at the treated sites by 35.3%. This policy would be cost-effective but would require very considerable capital expenditure (£11,000 per site).

6. Use of hot-rolled asphalt with high-PSV chippings at all nodes would reduce wet-road accidents by 11.6% and the cost would be very small (only £200 per site).

7. Use of resin/bauxite at the 20% of nodes with the highest numbers of wet-road accidents and hot-rolled asphalt with PSV 72 at the remaining sites would produce a reduction of 24.2% in wet-road accidents and give a net economic return of 50.4% per annum.

8. The recommended policy (for nodes as well as links) is to use high-PSV roadstone in routine resurfacing and to identify individual sites where the resin/bauxite treatment would be cost effective. Priority for treatment with resin/bauxite should be determined by ranking sites on the basis of benefit/cost ratio, following an assessment of the accident-saving potential at each site. The number of sites treated would depend upon the level of funding made available. This policy would be also appropriate for all urban classified roads in Great Britain.

CHAPTER 10

DISCUSSION AND CONCLUSIONS

10.1 DISCUSSION

This study has been concerned with investigating the problem of wet-road skidding in urban areas and assessing the potential for reducing accident rates by improving skid resistance. Most people, including many highway engineers, are unaware that skidding is a significant problem on urban roads and for a variety of reasons (discussed in Chapter 1) it has attracted little attention from highway engineers and research workers. The general assumption has been that skid resistance is important only on high-speed roads and that there is little scope for accident reduction by improving skid resistance on urban roads. The accident statistics presented in Chapter 2 show that, contrary to popular belief, there are actually more accidents with a reported skidding involvement on urban roads than on rural roads. The statistics show that an accident on a rural road is more likely to involve skidding, presumably as a consequence of the generally higher speeds on rural roads, but three-quarters of all accidents and 60% of wet-road skidding accidents are on urban roads. It is to be hoped that the publication of this study will lead to greater awareness of the scale of the urban skidding problem and the extent to which accident rates can be reduced by improving skid resistance.

One of the factors that has inhibited work in this field in the past is lack of data, viz.

- accident data in a readily accessible form,
- systematic measurements of skid resistance,
- information on sites where skid resistance has been changed on an experimental basis, so that the effect on accident rates can be observed.

It is fortunate that the Greater London Council has been in the forefront of developments that have provided the data necessary for the present study. The GLC has developed a computerised accident data bank with sophisticated retrieval and analysis facilities (described in Appendix A). It was the first local authority to acquire a SCRIM test vehicle (described in Chapter 3) for the routine monitoring of skid resistance of its road network. GLC SCRIM test results were used for the assessment of the skid resistance performance of various road surfacing materials (Chapter 4), for the accident-SFC correlation and regression studies (Chapters 6 to 8) and the assessment of the condition of Principal roads in London in relation to proposed national standards for skid resistance (Chapters 5 and 9). Despite the fact that the skidding rate in London has always been much lower than elsewhere the GLC has been active in the development of anti-skid surfacings (e.g. the resin/bauxite surface treatment process described in Chapter 4) and has used them extensively at accident sites. Most workers investigating the influence of skid resistance on accidents have not been able to conduct experiments and have, therefore, only been able to define associative relationships. The sites treated with anti-skid surfacing in London have, in effect, formed a large-scale experiment, whereby it has been possible to observe the effect on accident rates of a change in skid resistance at a large number of sites. Control sites used in assessing the effects of accident remedial measures are often unsatisfactory. The large GLC accident data bank provided a means of defining a group of control sites for each experimental site and this allowed adjustments to be made for changes which were not due to the treatment but were the result of the regression-to-mean effect (discussed in Chapter 7) or were a reflection of general trends in accident rates.

There is virtually no published information on urban skid resistance levels. This study has been based on GLC data for skid resistance and accidents but where possible the findings have been generalised to other urban areas.

The reported wet-road skidding rate (the proportion of wet-road accidents in which skidding is involved) is 44% on rural roads and 23% on urban roads. In London skidding is reported in only 10% of accidents on wet roads. Evidence was found (Chapter 7) that there is considerable under-reporting of skidding. The overall reduction in accidents observed at a large group of sites where the skid resistance had been increased was equal to three times the number of wet-road skidding accidents reported (in an equivalent period) before the improvement. This confirms that the incidence of skidding (or at least loss of adhesion between tyre and road) is greater than the reported rate. It means that the skidding problem is greater than the accident statistics suggest but it also means that the accident-saving potential is greater than has generally been supposed.

In Chapter 2 it was shown that in London the proportion of accidents in which skidding was reported does not vary greatly between the different classes of road but 84.2% of skidding accidents (and 83.5% of all accidents) are on the classified roads, constituting only 24% of the road length. Consequently, it was felt that attention should be directed mainly at these roads rather than the minor, unclassified roads. Particular attention was paid to approaches to pedestrian crossings and light-controlled junctions which together account for 28% of all wet-road accidents in London. The skidding rate at these locations is no higher than average but the high density of accidents means that the accident-saving potential per unit length of road is higher. In the system of standards proposed in LR510 (discussed in Chapter 5) approaches to traffic signals and pedestrian crossings on urban main roads are designated as high-risk locations, requiring high skid resistance. In practice, it is found that they are the areas where it is most difficult to maintain good skid resistance because they are on the more heavily-trafficked roads and are subjected to additional polishing stresses by traffic which is braking and/or turning.

The introduction of the SCRIM test vehicle has made it possible for a highway authority to measure the skid resistance of the whole of its main road network. From the review of test methods in Chapter 3 it is concluded that SCRIM is the best device for this purpose. Initially, there were doubts as to whether it would be possible to survey densely urban areas such as London because of the difficulty in maintaining the standard test speed and defined test path on congested roads. These difficulties have been overcome, mainly by operating late at night when the roads are clear. Experience has shown that SCRIM can satisfactorily perform its primary function of monitoring a route to identify sections which are relatively slippery in the wet. Care must, however, be exercised in interpreting the results, particularly if they are to be compared with standard target SFC values. Various adjustments to the SCRIM values may be required (e.g. speed correction) and allowance must be made for seasonal variation. The TRRL suggest that SCRIM values should be converted to standarised SFC values and that the network should be surveyed at least three times a year during the summer months to give Mean Summer SFC values. The practice adopted by most highway authorities, including GLC, is to carry out a single survey each year and to adjust the readings (on the basis of comparison with control sections) to give estimated mean summer values. In the light of all these adjustments, corrections and estimates and bearing in mind the poor test reproducibility (see 3.4.3), the confidence limits for the reported values are wide and allowance must be made for this if the results are to be compared with a precise target value. SFC values for Borough B which were used in part of the investigation into the relationship between SFC and accidents were all measured by one machine in one day and since they were used only on a comparative basis the test error (in this context) is very small. Other SFC values used in the study were adjusted (by comparison with control sections) to give Estimated Equilibrium Mean Summer SFC values. All SFC values mentioned in TRRL publications (e.g. LR504, LR510) are equilibrium mean summer values unless otherwise stated.

The survey into the skid resistance performance of hot-rolled asphalt on main roads in London showed that the SFC was on average 0.11 lower than would be predicted from the relationship between SFC, aggregate PSV and commercial vehicle flow defined in LR504. Possible reasons for the lower SFC values in London were discussed in 4.4 but the survey had not been carried out in sufficient depth to be able to establish the reasons positively and further work is required. The LR504 relationship was defined for rolling traffic on rural roads. The lower-than-expected SFC might be due to lower rate of spread of chippings in London, greater polishing action of slow-moving urban traffic or increased commercial vehicle axle loads. Whatever the reason, it is clear that only a moderate SFC can be maintained with hot-rolled asphalt on heavily-trafficked urban roads.

Conventional surface dressing, with a bituminous binder and crushed rock chippings, is commonly used on rural roads to restore skid resistance but has proved to be insufficiently durable for use on most main urban roads. Resin/bauxite surface dressing has been used extensively at accident sites in London. It gives a higher SFC than any other surfacing (0.65 on average at high-stress sites) and is extremely durable. It is, of course, a great deal more expensive than conventional surface dressing.

A wide range of wearing course materials and surface treatments is now available (see Chapter 4) which are durable and can provide intermediate levels of SFC. It is interesting to note that some of the materials (e.g. pervious macadam friction course, Delugrip, Ralumac, Erophalt surface dressing) gave SFC values similar to the values that would be predicted by LR504 for hot-rolled asphalt with chippings of similar PSV.

With the range of materials/treatments now available it is a simple matter to select the optimum treatment to achieve lowest-cost compliance with a target SFC value (up to 0.65) but in economic terms the value of the exercise is limited if the target value itself is not optimal. The optimum treatment is, in principle, that which is shown to be most cost-effective when treatment costs are compared with predicted savings in accident costs. In order to be able to predict the accident savings it is necessary to define the relationship between SFC and accident rate. The various sets of SFC standards which have been proposed (i.e. Giles, Marshall Committee, LR510) are all to some extent arbitrary and in no case did any of the authors claim that they are optimal SFC values.

The proposed standards are described in Chapter 5. One of the interesting features of the LR510 standards is the concept of Risk Rating, whereby the engineer assesses the relative accident risk at an individual site and assigns a risk rating which defines the target SFC. This system is much more flexible than the earlier proposals and gives the engineer the freedom to use his judgement in determining the appropriate target SFC value (within prescribed limits for the different categories of site). Very little guidance is given in LR510 on how to determine the risk rating at an individual site. Many engineers who have been endeavouring to implement the LR510 standards have either made a subjective assessment of risk rating or have developed a rigid system of assigning scores on the basis of the number of 'deficiencies' at the site. Methods of assessing accident risk were examined in Chapter 6. It was found that a subjectively-assessed risk rating correlates reasonably well with accident rate when only a few sites of similar character are involved but is unsatisfactory when large numbers of dissimilar sites are involved. Repeat assessments made after an interval of several weeks revealed that certain individuals can be highly inconsistent in their ratings. A set of objectively-assessed site parameters combined in a linear regression equation proved to be reasonably good as a predictor of total accidents. The most important parameters in the regression equation were found to be traffic flow, proportion of frontage occupied by shops, and presence of junctions. The addition of measured SFC to the predictor variables in the regression equation improved the correlation only slightly. Several features (e.g. low-radius bend, sub-standard road width) which are generally believed to be hazardous and are usually heavily weighted in both subjective and objective assessments are not actually associated with higher-than-average accident rates on roads in London. A possible explanation is that drivers are themselves aware that these features are potentially hazardous and so take extra care. It was found that examination of past accident history is the best method of predicting future accident rate at an existing site.

Of the three sets of standards discussed, only the set proposed by Giles is based upon investigation of accident risk in relation to SFC. He also considered the frictional demands of vehicles in braking and manoeuvring. The Marshall and LR510 standards are modified versions of the Giles standards. Giles's work was mainly on rural roads. He reported that at most of the skidding black spot sites which he examined there was a major geometric deficiency such as a low-radius bend or steep gradient. These deficiencies were present at only 3 out of 33 skidding black spots on Trunk and Principal roads in London which were described in Chapter 5. More than half the London black spots were at light-controlled junctions or uncontrolled pedestrian crossings (categories of site not mentioned by Giles). Thus skidding accident black spots in London are quite different in character from those described by Giles.

Giles calculated the relative risk of a site becoming the scene of repeated wet-road skidding accidents in relation to the SFC at the site. As shown in the curve in Fig.5.4, the risk increased very rapidly as SFC decreased. The curve suggests that at SFC 0.32 and below it was almost inevitable that the site would be a major skidding black spot. In Chapter 5 a similar exercise was performed on roads in London and a quite different relationship was found (also shown in Fig.5.4). The rate of increase in risk as SFC decreases is relatively small and there is no dramatic increase at very low SFC values. Very few, if any, of the sites with SFC below 0.32 could be described as skidding black spots. This indicates that skid resistance has much less influence on accident rates on roads in urban areas. Furthermore, the relationship between accidents and SFC is much less clear-cut on urban roads. This is probably a reflection of the much greater complexity of road-user interactions on these roads. The correlation and regression studies in Chapter 7 indicated that there is a statistically significant correlation between accidents and SFC but the relationship between the two parameters is imprecise. A precise relationship is, perhaps, not to be expected since skid resistance is only one of many factors which influence urban accident rates. Regression equations were developed defining the associative relationship between SFC and various accident parameters. The 338 sites at which SFC had been increased by the application of resin/bauxite provided a means of testing the predictive value of the regression equations. This proved to be extremely poor.

The important finding from the study of accident rates at the 338 sites before and after treatment was that increasing the SFC, from 0.35 to 0.65 on average, produced a net reduction of 34.9% in wet-road accidents. This reduction of 1.16% in wet-road accidents per 0.01 increase in SFC was used as a basis for estimating potential accident savings on urban classified roads generally. It was calculated that treating the whole of the urban classified road network in Great Britain to give the highest practicably-attainable SFC level would produce a reduction in wet-road accidents of 9,650 accidents per annum (including 2,750 in London). This is equivalent to a 15.5% reduction in wet-road accidents on urban roads generally and 5.0% of all urban accidents (all conditions). Unfortunately, in Chapter 9 it was calculated that the treatment cost would ~~would~~ be greater than the predicted saving in accident costs. Moreover, if a substantial proportion of the network were to be treated with resin/bauxite then it is likely that additional tyre wear would become a significant disbenefit which would need to be taken into account and this would further reduce the cost-effectiveness of this policy.

An increase in SFC could readily be achieved by conventional means simply by using roadstone of higher PSV. Average PSV values on urban main roads are approximately 60 in London and 55 elsewhere. An increase of 12 units in PSV would increase SFC by 0.10 and this would give an estimated reduction of 4,196 accidents per annum on urban classified roads (including 1,185 in London). This is equivalent to a reduction of 11.6% in wet-road accidents on the treated roads, 6.7% of urban wet-road accidents and 2.2% of all urban accidents. If the higher-PSV roadstone were to be introduced when the road is resurfaced routinely (and assuming that the wearing course is hot-rolled asphalt with a 20-year life) the additional cost would amount to only £950 per km. The predicted saving in accident costs is £1090 per km per annum. Thus, the additional cost would be recovered within one year and the benefits would continue throughout the life of the surfacing. Discounting the 20-year accident savings at 7% gives a total net return of 1200% (60% per annum). This policy is exceptionally cost-effective and, furthermore, would involve only a small increase in resurfacing costs (only 4% extra in London).

Although it was shown that treatment of all urban classified roads with resin/bauxite would not be justifiable in economic terms, the treatment of selected locations can be highly cost-effective. For example, the discounted saving in accident costs at the 338 experimental sites was 6.4 times the treatment cost. It was estimated that in London 16% of Non-Trunk nodes have already been treated and there is justification for treatment of a further 38%. Treatment would be justified on 24% of Principal road links and 9% of Non-Principal links. Outside London accident densities are lower and treatment would be justified at a smaller proportion of sites.

At a substantial number of the experimental sites, including some where the SFC had been extremely low, the large increase in SFC did not reduce the accident rate. This is further evidence that there are many urban locations, including some major conflict areas, where SFC has little influence on accident rate. Further work is necessary to define the characteristics of such sites so that unnecessary expenditure on improving skid resistance can be avoided. In terms of LR510, this means that they should be assigned an appropriately low risk rating and it is suggested that LR510 should be modified so that the full range of risk ratings is available for any site regardless of category. The present range of risk ratings for category A1 sites is 6 to 10, with target SFC values 0.55 to 0.75. Of the 71 conventionally-surfaced nodes in Borough B, 66 were category A1 sites and none of these was within the required SFC range. The mean SFC value was only 0.35 but at more than 50% of the sites it was found that there was on average less than one wet-road accident per annum. Clearly, the low SFC at many of these sites has not constituted a hazard and they should be assigned a risk rating lower than the LR510 minimum of 6.

In Chapter 8 consideration was given to criteria for selecting sites for treatment with resin/bauxite. From examination of the results of the experimental sites it was concluded that, in the context of a network where SFC levels are generally low, very low SFC is a poor selection criterion. Sites with very low SFC should be given priority for treatment only if there is evidence of an associated wet-road accident problem, i.e. if the percentage of accidents in the wet is significantly higher than average or if wet-road skidding or shunt accidents have been reported.

The assessment of SFC levels on Principal roads in Borough B (described in Chapter 9) showed that 99% of conventionally-surfaced nodes and 75% of link sections did not comply with the requirements of LR510. On the basis of the SFC-PSV-traffic relationship defined by TRRL compliance would be feasible using hot-rolled asphalt with chippings of appropriate PSV (up to PSV 72 which is the maximum available for durable, natural roadstone) at 98% of link sections. The survey of the performance of hot-rolled asphalt in London (Section 4.4) indicates that on present standards compliance would be achievable at only 76% of link sections. It was shown that compliance is feasible at fewer than 40% of nodes. Clearly, full compliance is not possible with hot-rolled asphalt on many heavily-trafficked roads. The use of special surfacings such as pervious macadam friction course or Delugrip might give compliance at a some sites but at others it would be necessary to use resin/bauxite surface dressing. Even with resin/bauxite compliance cannot be assured at all sites, since the average SFC value on this material is 0.65 whereas the required value at the highest-risk sites is 0.70 or 0.75. It was shown that a policy of aiming for substantial compliance with LR510, using hot-rolled asphalt where possible and resin/bauxite at the remaining sites would, in fact, be cost effective in Borough B and would reduce wet-road accidents by an estimated 23% at nodes and 15% on links . Additional accident savings could be achieved at very little cost by using the highest-PSV roadstone at allthe hot-rolled asphalt sites rather than stone with the precise PSV required to attain the target SFC. The cost per accident saved is very much greater at resin/bauxite sites compared with hot-rolled asphalt sites (see Sect. 9.6 and Table F.2). Few highway authorities would wish to, or would have sufficient funds to, spend very large sums on resin/bauxite simply to achieve compliance with LR510. The use of this expensive treatment should be confined to locations where it can be demonstrated that the the likely saving in accident costs would exceed the treatment costs. Candidate sites for resin/bauxite treatment should be ranked on the basis of benefit/cost ratio and this would determine priorities for treatment. It was shown in Chapters 7 and 8 that it is very difficult to reliably predict accident savings that would result from the improvement of skid resistance at an individual site and further work is needed to define the functional relationship between SFC and accidents on urban roads.

The study of SFC levels and accidents on Principal roads in Borugh B involved consideration of various alternative policies for improving skid resistance. It was concluded that the most satisfactory policy, which is applicable to all urban classified roads, is to improve the general level of skid resistance by using high-PSV (70-72) chippings when a road is to be resurfaced (or surface dressed) routinely and to undertake a programme of skid resistance improvement at selected locations using anti-skid treatments such as resin/bauxite surface dressing. This policy would produce a substantial reduction in wet-road accidents. The additional cost of using higher-PSV roadstone would be very small. It has been demonstrated that, although the resin/bauxite treatment is relatively expensive, it can be highly cost-effective. The scale of the anti-skid surface treatment programme undertaken by an individual highway authority will depend upon the level of funding which is made available and this will depend upon the degree of political commitment to reducing the accident toll on urban roads.

10.2 SUGGESTIONS FOR FUTURE WORK.

1. Relationship between SFC, PSV and traffic flow.

The survey described in Chapter 4 on the SFC performance of hot-rolled asphalt in London was only a pilot study. It was intended to conduct a much more extensive survey but time did not permit this. The survey clearly established that SFC levels on main roads in London are much lower than would be expected on the basis of the relationship between SFC, aggregate PSV and commercial vehicle flow defined in LR504 by Szatkowski and Hosking but it was not possible to investigate the reasons for the lower SFC values. Three possible reasons (discussed in 4.4) are that rates of spread of chippings (in hot-rolled asphalt) are lower on urban roads compared with the rural roads for which the LR504 relationships were developed, that present-day commercial vehicles exert a greater polishing effort than in the early 1970's when the LR504 studies were carried out, and that the polishing action of vehicles on urban roads is more severe because of the lower vehicle speeds and greater frequency of braking. All these factors need to be investigated so that the appropriate PSV can be selected to achieve a given target SFC value.

2. Performance of 'intermediate' surfacing materials.

Further work is required on evaluating the SFC performance, durability and whole-life costs of materials which are intermediate between hot-rolled asphalt and resin/bauxite surface dressing. A preliminary assessment of some of these materials (Delugrip, Ralumac, pervious macadams, Erophalt surface dressing) was made in Chapter 4 but the number of trial sites involved was relatively small. An evaluation is also desirable of the shot-blasting process mentioned in 4.7 for retexturing road surfaces. There have been developments in this field recently and the process could have a useful role to play in restoring both microtexture and macrotexture but more information is needed on the effectiveness in improving low-speed skid resistance, the length of time for which the improvement is sustained and the number of times that it can be repeated.

3. Tyre wear.

It is known that tyre wear increases with increasing microtexture (Chapter 4) and if widespread skid resistance improvements are implemented this could become a significant disbenefit which would to some extent offset the saving in accident costs. Work is needed to examine rates of tyre wear on different road surfaces and to estimate additional tyre wear costs.

4. Risk rating.

In Chapter 6 an attempt was made to devise a method for assessing accident risk on the basis of objectively-assessed site parameters. This was not particularly successful. The analytical methods used were relatively simple, involving additive linear regression models. A more sophisticated analysis (e.g. factor analysis, polynomial regressions) might be more fruitful. Major intersections were excluded from the study in Chapter 6 because of the complex nature of the road-user interactions at these locations but they are, of course, an important part of the network and should be included in any future study.

5. Locations not influenced by SFC.

There were strong indications in this study that there are certain locations, including some major conflict areas, where skid resistance has no appreciable influence on accidents. It would be of great benefit to identify such sites so that unnecessary expenditure on improving skid resistance can be avoided. A further study is needed to define the characteristics of these sites, possibly taking into account factors such as vehicle speed which were not considered in the present study.

6. Relationship between SFC and accident rate.

The regression equations developed in Chapter 7 were statistically significant but were imprecise and therefore of limited predictive value. Their functional validity was assessed by comparing predicted and actual changes in accident rate when SFC was increased at a group of light-controlled junctions and pedestrian crossings. The correlation between predicted and actual change proved to be extremely poor. This could have been due to the fact that the regression equations were developed for lengths of road which were not major conflict points (except for a small number of sections in which there was a pedestrian crossing) and so were dissimilar to the locations at which the regression equations were tested. There is very little information on accident changes on lengths of road where the SFC has been changed but a study of such lengths would be desirable.

7. Regression-to-mean.

In Chapter 7 the regression-to-mean effect in relation to accident rates at individual locations was discussed and a method was devised for compensating for this effect on the experimental sections. The effect has long been recognised and it is important that allowance should be made for it when selecting sites for remedial treatment as well as in assessing the effects of treatment. Further work is necessary, e.g. to examine year-to-year variation in accident rates at individual sites in relation to the long-term accident rate.

8. Data from areas other than London.

All the detailed information on accidents and SFC in this study was from London which is different in many respects from other urban areas. It would be desirable to repeat this study using data from other urban areas in Great Britain.

10.3 CONCLUSIONS.

1. Wet-road skidding is not, as is a generally believed, a problem confined mainly to rural roads; 60% of all reported wet-road skidding accidents are on roads in built-up areas. Although levels of frictional demand are generally low on urban roads, skidding is reported in 23% of wet-road accidents in these areas. (2.4, 3.2)

2. The reported wet-road skidding rate in London (only 10% in 1980) is much lower than the national urban average but there is evidence that the true skidding rate is considerably higher than the reported rate. Improvement of skid resistance at a large group of sites produced a reduction in accidents which was three times as large as the number of skidding accidents reported in the pre-treatment period. This indicates substantial under-reporting of skidding and means that the potential for saving accidents by improving skid resistance is much greater than the statistics might suggest. (2.4, 7.2)

3. In London 84% of wet-road skidding accidents are on the classified roads, which constitute only 24% of the road length. 28% of skidding accidents are in the vicinity of pedestrian crossings or light-controlled junctions. (2.5)

4. The SCRIM test vehicle is the best device for routine measurement of skid resistance to identify sections of urban road which are relatively slippery but, if the results are to be compared with precise target mean summer SFC values, allowance must be made for the wide confidence limits about the test results. (3.4)

5. SFC values on main roads in London are approximately 0.1 lower than predicted from the relationship between SFC, aggregate PSV and commercial vehicle flow defined in LR504. This is possibly due to a lower rate of spread of chippings in the standard hot-rolled asphalt surfacing but may also be a consequence of the slow-moving urban traffic having a greater polishing effect. Furthermore, it is possible that the polishing effect of the 'average' commercial vehicle has changed since the publication of LR504. (4.4)

6. Many of the cheaper surfacings that are used on rural roads are unsuitable for urban main roads because of inadequate durability under more arduous conditions. Hot-rolled asphalt is the most suitable wearing course surfacing for general use on urban main roads but cannot maintain a high SFC at heavily-trafficked locations. Epoxy resin/calcined bauxite surface dressing is durable and gives the highest attainable skid resistance on heavily-trafficked roads (SFC 0.60 - 0.75). A wide range of wearing course materials and surface treatments is now available which can provide intermediate levels of skid resistance. (4.4 to 4.7)

7. In economic terms the optimum material for use at a site where the SFC is to be improved is not necessarily that which will produce the lowest-cost compliance with a standard target SFC level but is that which is shown to be the most cost-effective when treatment costs are compared with predicted savings in accident costs. (8.1)

8. Examination of past accident data is the best method of assessing future accident risk at an existing site. Subjective assessment of relative accident risk can be reasonably good when only a small number of sites of similar character are to be compared but is unsatisfactory when large numbers of dissimilar sites are involved. If past accident records are not available or are no longer relevant the best alternative is to use objectively-assessed site parameters as predictor variables in a linear regression equation. For predicting relative accident totals on main roads in London the most important parameters are traffic flow, proportion of frontage occupied by shops, and presence of junctions. Site geometry (curvature, gradient, etc.) is of little significance. Measured skid resistance is a poor predictor of skidding accident risk. (Chapter 6)

9. Giles's finding (based on rural data), that the relative risk of a site becoming the scene of repeated wet-road skidding accidents increases rapidly as SFC decreases, is not valid for roads in London. A very low skid resistance does increase the overall risk of skidding accidents but by a much smaller extent than suggested by Giles. (5.2)

10. Low skid resistance is not necessarily a hazard. There are many locations where skid resistance has little or no influence on accident risk. At a substantial proportion of sites in London (including LR510 category A1 sites) with low SFC the accident rate is not unduly high. At about one-third of 338 sites treated with resin/bauxite there was no reduction in accidents, despite the fact that the SFC before treatment was generally very low. If LR510 is to be used as a basis for determining target SFC values it should be amended so that the full range of Risk Ratings (and corresponding target SFC values) is available for any location regardless of site category. If the accident rate at a category A site is demonstrably low then it should be assigned an appropriately low risk rating. When deciding whether an improvement in skid resistance is necessary at an individual site the adequacy of the present SFC is best judged by the accident history rather than by reference to the proposed national SFC standards. Low skid resistance alone is a poor indicator of the need for anti-skid treatment. There is a greater likelihood of a significant accident reduction at sites where there is evidence of an associated wet-road accident problem (e.g. where the proportion of accidents in the wet is significantly higher than average or where skidding accidents have been reported). (7.2, 8.3)

11. Regression equations have been developed defining the associative relationship between SFC and various accident parameters. Although the relationships thus defined were statistically significant they proved to be of little value in predicting the effect on accident rate of a change in SFC. The correlation was extremely poor between observed change in accident rate at individual sites, following an increase in skid resistance, and change predicted by the regression equations. (Chapter 7)

12. At 338 sites where the SFC was increased from an average of 0.35 to 0.65 by the application of resin/bauxite surface dressing there was a net reduction of 34.9% in wet-road accidents. Dry-road accidents fell by only 1.2%. (7.2)

13. The reduction in wet-road accidents of 1.16% per 0.01 increase in SFC observed at the 338 'experimental' sites was used as a basis for estimating potential accident savings on urban classified

roads. It was estimated (from 1980 accident statistics) that use of the resin/bauxite treatment throughout the urban classified road network in Great Britain would reduce wet-road accidents by 9,650 (26.8%) per annum. This reduction represents 15.5% of wet-road accidents on all urban roads (classified and unclassified) and 5.0% of all urban accidents (all conditions). Use of the resin/bauxite to improve skid resistance on these roads would reduce the national accident total by 3.8%. However, it has been demonstrated that such an approach would not be cost-effective. (8.1, 9.2)

14. When used selectively the resin/bauxite treatment can be highly cost-effective. At the 338 'experimental' sites the saving in accident costs was 6.4 times the cost of treatment. In London 16% of nodes (intersections between classified roads) have been treated and it has been shown that there is economic justification for treating a further 38.5%. On the remainder of the classified Non-Trunk road network treatment is justified on 24% of the Principal road length and 9% of the Non-Principal road length. (9.3)

15. The use of natural roadstones with greater resistance to polishing would be extremely cost-effective. On urban classified roads the use of a roadstone of PSV 12 units higher would on average increase the SFC by 0.10 and would give an estimated total saving in accident costs equivalent to 13 times the additional cost of the higher-PSV stone. The additional expenditure involved would be relatively small. In London, for example, the use of chippings of PSV 72 rather than 60 would add only 4% to the cost of a hot-rolled asphalt wearing course. (9.5)

16. Based on findings relating to Principal roads in a typical London borough, compliance with LR510 is achieved at very few category A sites and only 25% of category B sites. Substantial compliance can, in principle, be achieved at category B sites using hot-rolled asphalt with chippings of appropriate PSV and this would be highly cost-effective. The use of the highest-PSV natural roadstone (PSV 72) at all category B sites would also be cost-effective and would give a greater reduction in accidents. Compliance is feasible using conventional surfacing at less than

40% of category A sites; the remainder would require a special surfacing such as resin/bauxite at considerably greater cost. Use of the resin bauxite would be cost-effective at category A sites in London but not necessarily so in areas where accident densities are lower (but see 17 below). (9.6)

17. The target SFC for LR510 category A1 sites ranges from 0.55 to 0.75 depending on risk rating. The average SFC achieved at such sites with resin/bauxite is 0.65. Therefore, even with resin/bauxite, compliance cannot be assured at the higher target levels. (In fact compliance was not achieved at 24% of resin/bauxite sites). It is suggested that the maximum target SFC should be reduced to the more realistic level of 0.65. (9.6)

18. It is proposed that high-PSV roadstone (PSV 70-72) should be used on all urban main roads as a matter of routine. This would reduce wet-road accidents on these roads by more than 10%. Studies should be carried out to identify those locations where further accident reductions can be achieved cost-effectively by using treatments such as the resin/bauxite surface dressing. The scale of the treatment programme will depend upon the level of funding made available. Treatment priorities should be established by ranking on the basis of benefit/cost ratio. This approach requires a more precise quantitative definition of the relationship between SFC and accident rate, and a better understanding of the performance and durability of alternative treatments. Both these areas require further work. It is only by achieving an ability to evaluate 'whole life' costs and benefits that an assessment of overall economic optimisation can be made.

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APPENDIX A

THE GLC ACCIDENT DATA STORAGE AND RETRIEVAL SYSTEM (ACCSTATS)

1 DATA INPUT

The Metropolitan Police are required to submit to the Department of Transport details of all personal injury accidents which are reported to them. Details of each accident are recorded on a nationally standardised form known as Stats 19 (shown in Fig 1 of Chapter 2). The information on the Stats 19 form is intended mainly for use by Central Government for statistical purposes but is made available to highway authorities and is the principal source of data for engineers engaged in accident prevention.

The Stats 19 form is designed so that the accident details can be entered in coded form to facilitate subsequent processing by computer. It has sections for recording details of the casualties (e.g. age, sex, severity of injury) the vehicles involved (e.g. vehicle type, manoeuvres, skidding involvement) and the attendant circumstances (e.g. date, time, location, weather). The details are extracted from the report which is prepared by a police officer either at the scene, if the police have been called, or at the police station if the accident is reported by one of the drivers involved. Each accident is given a unique reference number incorporating a code indicating the police division. At the police headquarters the accident is pinpointed on a large-scale map and hence the grid-reference and route number are defined. This completes the information required by the Department of Transport. The details are then transferred to computer tapes which are submitted to the DTp, with copies to the GLC. Subsidiary information for local use (e.g. a plain language description of the location) is also prepared and is linked to the basic data using the unique accident reference numbers.

The accident details are stored on the GLC computer and can readily be retrieved. The full details of a particular accident can be listed if the reference number is known; all accidents in a particular area or of a particular type may be listed; statistical summaries may be produced.

Details of all reported personal injury accidents occurring within the GLC area (excluding the City of London) since January 1st 1970 are held in the GLC computer.

2 LOCATION NETWORK

It is often useful to be able to relate accidents at particular locations to other important parameters such as traffic flow, vehicle speed or road condition and a number of highway authorities have established computerised data banks to hold such information. To do so it is necessary to devise a location system and to define the road network in terms of that system. The location system used by the GLC for main roads in London consists of nodes and links; a node is a junction between two classified roads and a link is the section of classified road joining two nodes. Within each borough (of which there are 32 in London) each node has a unique three-digit reference number. The reference number of a link is simply the combination of the reference numbers of the nodes at either end of the link. A network file is held on the computer that includes the description and grid reference of each node and the route number and length of each link. The remaining roads (the minor roads) are assigned to a system of cells. Each cell is a half-kilometre square, identified by the grid reference of its south-west corner. In assigning an accident to the network the computer first attempts to assign it to a node, then to a link, then to a cell. To be assigned to a particular node it must have occurred within 20 metres of a junction and have a grid reference that places it within 50 metres of the centre of the node. To be assigned to a particular link it must have the correct route number and have a grid reference which places it within 50 metres of the centre line of the link. If it cannot be assigned to a node or a link it is filed to the cell defined by its grid reference. Over 80% of the accidents in London occur on the main road network defined by the node and link system.

3 DATA OUTPUT

The accident data may be output as a series of standard tabulations or listings routinely-produced monthly, quarterly or annually, or as one-off retrievals by request for special investigations. The computer can output the data in printed form or on microfilm, or it can be viewed on a VDU (visual display unit).

3.1 Routine output.

Accident summaries for each borough are produced at monthly intervals giving a brief description of the individual accidents. Tabulations are produced quarterly and annually, breaking down accident, casualty and vehicle details in each borough according to time of day, severity of injury, type of vehicle, etc.

Other tabulations are produced which carry additional information on the geographical distribution of the accidents. This is achieved by merging the accident data file with the network file to assign each accident record to a location on the network. One table lists all accidents (by reference number) occurring at each node, link and cell and also prints a brief summary of these accidents. Another, known as the 'Black Spot Table', lists the locations at which the greatest numbers of accidents occur, indicating the relative occurrence of certain features in the accidents (e.g. pedestrian involvement, skidding).

3.2 Special retrievals

Three basic forms of retrieval are available. The first is a listing of accidents at particular locations, the second is a facility for producing special tabulations and the third is a computer-plotted map overlay showing the locations of individual accidents.

A listing can be produced giving full details of all accidents at a particular location in a specified period of time.

A listing can be produced in which each link is divided into 100-metre sections (with adjoining sections overlapping by 50 metres) and the total number of accidents in each section is given for any specified year. This was used to obtain the accident data for the 268 sections of road in Lambeth which were examined in Chapter 6.

A tabulation facility exists which enables the user to select accidents, casualties or vehicles involved in accidents, according to desired criteria and then tabulate them according to further criteria.

This is particularly useful for statistical investigations and was used for many of the tables shown in Chapter 2.

In the later stages of this study a further facility became available which enables accident totals at a specified location to be tabulated in user-defined categories. The location may be defined as a section of road between points A and B within a link (with the user defining the co-ordinates of A and B) or as all points within a specified radius of a particular point (of specified co-ordinates). This facility was used to obtain the data for comparing before and after accident characteristics at sites where the skid resistance had been changed (Chapter 7).

The map overlay facility is extremely useful for identifying accident clusters; an example is shown in Figure 1 of Chapter 5. The overlay is produced by a computer-controlled plotter. The location of each accident is plotted as a symbol on a transparent sheet, using the assigned grid reference to define the co-ordinates. The usual scale of the overlay plot is 1:10,000 but this can be varied to suit the scale of the map on which it is to be placed. Different coloured pens can be used to distinguish between different types of accidents.

APPENDIX B

ESTIMATION OF EXCESS ACCIDENTS IN WET WEATHER

APPENDIX B. ESTIMATION OF EXCESS ACCIDENTS IN WET WEATHER.

The purpose of the exercise was to estimate the excess number of accidents in London which could be attributed to the road being wet. The principle of the method was to establish the average accident rate on dry days, then calculate the accident total that would be expected if all the days were dry; the difference between the estimated total and the actual total gives the excess number of accidents due to rain (and snow/ice). In order to eliminate seasonal effects (variation in daylight hours, traffic flows, duration of time for which road is wet, etc.) each month was considered separately.

A listing was produced from ACCSTATS showing accident totals on dry, wet and snow/ice covered roads for each day in the twelve years 1970-81. The listing was examined to identify 'dry' days which were defined as days on which all the accidents were reported as being on dry roads (i.e. 0 wet-road and 0 snow/ice accidents). These days were then grouped by month. Unfortunately, wholly dry days were found to be extremely rare in London during the winter months. In the whole twelve-year period there were only two January days without wet or snow/ice accidents. Clearly, this was an insufficient number of days to use for establishing a reliable mean dry-day accident rate for January. It was, therefore, decided to widen the definition of a dry day to include days on which there were 0-2 accidents on wet roads or on snow/ice. The average daily accident total in London during the study period was 135.

Table B.1 shows monthly 'dry' day accident rates, monthly accident totals (actual and expected) and estimated excess accidents due to rain and to snow or ice. It will be seen that there were an estimated 67,081 excess accidents in the twelve-year period - equivalent to 12.8% of the expected accident total.

It is difficult to separate from the excess accidents those due to snow/ice because, whereas rainfall does not deter road users to any great extent in London and exposure levels are reduced only slightly in the wet, snow does substantially reduce traffic levels. Consequently, although snow and ice-covered roads are more hazardous, actual numbers of accidents are lower than on dry days. The 7,893 accidents on snow/ice represent only 1.3% of all accidents (see Table

8 in Chapter 2). It is reasonable to assume that a high proportion of these accidents are attributable to the presence of the snow or ice. If it is assumed that none of the accidents would have occurred but for the snow/ice then the excess attributable to wet weather is 59,188 which is equivalent to 11.3% of the expected number of accidents in all conditions and 61% of expected wet-road accidents (expected number = actual number in wet minus 59,188 excess).

The excess wet-road accident numbers are greatest in January and December when the roads are wet for a high proportion of the time and there are more hours of darkness, and are lowest in June and July.

TABLE B.1

Estimation of excess accidents due to rain, snow, ice

	'DRY' DAYS IN 1970-81			ALL DAYS IN 1970-81			
	n OF	n OF	ACC. PER	n OF	n OF ACCIDENTS		
MONTH	DAYS	ACCIDENTS	'DRY' DAY	DAYS	EXPECTED	ACTUAL	EXCESS
Jan	17	1,671	98.3	372	36,568	48,221	11,653
Feb	34	3,687	108.4	339	36,748	43,623	6,875
Mar	76	9,367	123.3	372	45,868	49,480	3,612
Apr	126	14,458	114.7	360	41,292	46,274	4,982
May	142	17,931	126.3	372	46,984	50,521	3,537
Jun	171	21,893	128.0	360	46,080	47,482	1,402
Jul	184	23,058	125.3	372	46,612	48,692	2,080
Aug	175	20,420	116.7	372	43,412	45,882	2,470
Sep	163	21,017	128.9	360	46,404	50,170	3,766
Oct	99	13,587	137.2	372	51,038	54,965	3,927
Nov	31	3,946	127.3	360	45,828	55,501	9,673
Dec	19	1,995	105.0	372	39,060	52,164	13,104
TOTAL	1,237	153,030	123.7	4,383	525,894	592,975	67,081

NOTE: A 'dry' day is one on which there were 0-2 wet road accidents and 0 snow/ice accidents.

APPENDIX C

DATA FROM SURVEY OF PSV, SFC AND TRAFFIC

(Chapter 4)

Table C.1 Coded data for 65 sites.

VARIABLE		COLUMNS
SITE -	....	1 - 2
BOROUGH -	....	4 - 5
LINK -	....	7 - 12
SFC -	Estimated equilibrium mean summer SFC	14 - 18
TRAFFIC -	Commercial vehicle flow (thousands) per day ...	21 - 23
CHIPPING-	Source of chipping (actual quarry)	25 - 25
PSV -	Polished Stone Value	27 - 28
TEXTURE -	Texture depth (low, medium, high)	30 - 30
DENSITY -	Proportion of surface covered by chippings	32 - 33

1	9	287298	0.320	2.3	C	60	H	70
2	8	292754	0.212	1.7	D	52	L	55
3	8	293295	0.349	2.0	E	50	M	60
4	8	284295	0.360	1.9	B	59	M	65
5	8	284286	0.362	1.9	G	67	L	70
6	8	294802	0.304	1.4	D	52	L	65
7	8	287296	0.342	2.5	D	52	H	60
8	8	278287	0.300	2.2	B	59	H	70
9	8	278279	0.280	2.2	B	59	L	65
10	8	279811	0.329	2.2	B	59	M	70
11	8	234811	0.290	2.3	D	52	L	55
12	8	222234	0.304	2.2	E	50	M	70
13	8	181758	0.260	2.3	D	52	L	55
14	8	178179	0.304	1.9	D	52	M	60
15	8	141154	0.321	1.4	D	52	M	60
16	8	127744	0.381	3.9	B	59	L	60
17	8	179213	0.246	4.3	D	52	M	60
18	8	213248	0.318	2.8	D	52	M	65
19	8	240241	0.329	2.9	B	59	H	65
20	8	811816	0.334	3.2	D	52	L	65
21	8	211221	0.276	1.6	D	52	M	65
22	5	068085	0.269	2.9	D	52	L	80
23	5	109111	0.423	3.0	B	59	M	65
24	5	111129	0.487	3.0	G	67	L	65
25	5	156169	0.298	2.5	D	52	M	60
26	5	156157	0.384	4.3	B	59	M	60
27	27	144179	0.371	1.8	W	55	M	65
28	27	043144	0.373	1.4	W	55	M	65
29	27	008011	0.361	0.6	B	59	M	65
30	10	226227	0.402	1.9	T	57	L	65
31	10	202214	0.405	1.1	T	57	L	65
32	10	708709	0.426	1.6	T	57	M	65
33	10	129660	0.415	1.1	B	59	M	60
34	10	074087	0.412	1.1	B	59	M	60
35	10	160641	0.295	2.3	B	59	M	65

Table C.1 (continued)

36	10	162641	0.298	3.5	B	59	M	70
37	10	081104	0.346	2.5	T	57	M	65
38	10	114739	0.283	1.8	E	50	M	60
39	10	026061	0.263	1.5	E	50	M	65
40	10	026061	0.332	1.5	T	57	M	65
41	10	016026	0.383	1.5	T	57	M	65
42	10	008024	0.287	1.0	E	50	M	60
43	10	160233	0.306	1.2	B	59	M	60
44	9	048062	0.428	1.9	G	67	M	65
45	9	079091	0.328	1.9	F	45	L	65
46	9	124125	0.468	1.7	G	67	M	65
47	9	209211	0.378	1.2	C	60	M	65
48	9	204211	0.357	1.3	C	60	M	65
49	9	204742	0.358	1.2	C	60	M	65
50	9	155157	0.371	1.5	C	60	M	65
51	9	157159	0.403	1.0	C	60	M	65
52	9	163188	0.283	2.0	C	60	M	65
53	9	117118	0.331	1.5	E	50	M	60
54	22	178717	0.317	1.2	E	50	L	60
55	22	182635	0.343	1.0	E	50	L	70
56	22	046051	0.349	1.1	E	50	M	70
57	22	051706	0.362	0.7	E	50	M	70
58	22	126702	0.492	1.1	G	67	L	65
59	22	126702	0.353	1.1	E	50	M	65
60	25	011739	0.451	1.3	K	67	M	70
61	25	008751	0.481	2.9	K	67	M	70
62	25	009020	0.461	2.9	K	67	M	70
63	25	011738	0.458	0.8	K	67	M	70
64	5	031703	0.450	2.2	K	67	M	70
65	5	703812	0.470	2.2	K	67	M	70

APPENDIX D

ACCIDENT RISK SURVEY DATA

Table D.1 Coded site parameters for 268 study sections.

VARIABLE			COLUMNS
CASENO	-	Case number	1 - 3
LINK	-	Link number	4 - 9
SECTN	-	Location of section within link	10 - 13
HOUSNG	-	Proportion of frontage occupied by housing	14 - 15
SHOPS	-	Shops	16 - 17
COMM	-	Commercial property	18 - 19
INDUST	-	Industrial buildings	20 - 21
PUBLBG	-	Public buildings	22 - 23
SCHOOL	-	Schools	24 - 25
OPENSP	-	Open space	26 - 27
VACANT	-	Vacant plot	28 - 29
OTHER	-	Other	30 - 31
PELICN	-	Number of pelican crossings	32 - 32
ZEBRA	-	Zebra crossings	33 - 33
BUSSTP	-	Bus stops	34 - 34
GARAGE	-	Petrol stations	35 - 35
PUB	-	Public houses	36 - 36
TJCT1	-	T or Y-junctions (1 - 100 veh./day)	37 - 37
TJCT2	-	T or Y-junctions (101-1000 veh./day)	38 - 38
TJCT3	-	T or Y-junctions (1001-5000 veh./day)	39 - 39
TJCT4	-	T or Y-junctions (over 5000 veh./day)	40 - 40
XRD1	-	Crossroad junctions (1 - 100 veh./day)	41 - 41
XRD2	-	Crossroad junctions (101-1000 veh./day)	42 - 42
XRD3	-	Crossroad junctions (1001-5000 veh./day)	43 - 43
XRD4	-	Crossroad junctions (over 5000 veh./day)	44 - 44
ACCSS1	-	Private accesses (1 - 2 veh./day)	45 - 45
ACCSS2	-	Private accesses (3 - 50 veh./day)	46 - 46
ACCSS3	-	Private accesses (51 - 100 veh./day)	47 - 47
ACCSS4	-	Private accesses (over 100 veh./day)	48 - 48
ONEWAY	-	One-way traffic flow	49 - 49
LANES	-	Number of lanes	50 - 50
BUSL	-	Bus lane	51 - 51
WIDTH	-	Road width (metres)	52 - 53
BEND	-	Bend (degrees)	54 - 55
GRAD	-	Gradient (percent)	56 - 56
LRCAT	-	LR510 site category	57 - 57
RRLR	-	Risk rating type LR	58 - 58
RRY	-	Risk rating type Y	59 - 59
SFC	-	SFC (x100)	60 - 61
SFCDEV	-	Standard deviation of SFC	62 - 63
PREACC	-	Previous accident total (1972-1976)	64 - 65
TOTACC	-	Total number of accidents (1977-1981)	66 - 67
WETACC	-	Number of wet-road accidents	68 - 69
WETSKD	-	Number of wet-road skidding accidents	70 - 71
TRAFF	-	Total daily vehicle flow in thousands	72 - 73

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  5 17019  50 0 2 0 0 3 0 5 0 00020001000000000016018 8134445 2 8 4 3 245
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  8 25026 250 5 1 0 2 2 0 0 0 00050000000000003016018 0034536 22824 3 039
  9 48062  50 0 9 0 0 1 0 0 0 0100000110000000001401212016625 21515 4 038
 10 48062 150 0 9 0 0 1 0 0 0 0014000000000000001601814116640122946 4 038
 11 48062 250 0 8 2 0 0 0 0 0 000010020000000000160182113553 4 3335617 138
 12 48062 350 010 0 0 0 0 0 0 00000001000000000016018 0235551183624 2 038
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 14 93097 15010 0 0 0 0 0 0 0 000000000000000100120 9 1132236 11528 7 023
 15 93097 25010 0 0 0 0 0 0 0 000000000000000000120 8 4132233 2 4 2 0 023
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 18 93097 550 5 0 0 0 0 0 5 0 000000000000000000120 810033436 2 2 0 0 023
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 21 93097 85010 0 0 0 0 0 0 0 000000000000003000120 8 8433438 2 2 0 0 023
 22 52070  50 0 9 1 0 0 0 0 0 000000020000000002010 715335536 3 8 7 2 015
 23 52070 150 0 9 0 1 0 0 0 0 001000020000000110010 7 7117741 2 4 6 0 015
 24 52070 250 0 5 0 0 1 0 4 0 000101200000000200010 7 1535538 1 8 7 0 015
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Table D.1 (continued)

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27157159	50 0 0 0 0 0 010 0	0001000000000000014010	0032238	3 1 2 2	019
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30157159	350 0 0 0 0 0 010 0	0001000000000000014010	0032235	2 6 1 0	019
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32163188	150 0 9 1 0 0 0 0 0	0011000200000001014012	0218830	31726 6	039
33163188	250 0 5 5 0 0 0 0 0	0001100200000010213110	0236632	14429 8	039
34163188	350 0 7 2 0 1 0 0 0	0000000200000010013111	0235532	2262611	139
36188216	50 7 0 0 0 3 0 0 0	0000000100000031012213	1032240	6 2 6 2	044
37188216	150 5 0 3 0 2 0 0 0	0000100000000030212215	3132236	4 2 3 2	044
38188216	250 5 0 2 2 1 0 0 0	0000100000000021112216	3233341	1 612 1	044
39216217	50 5 0 4 0 1 0 0 0	0001100200000210213113	0133331	4 6 3 3	245
40216217	150 6 4 0 0 0 0 0 0	0000000100000010012215	0135531	32126 2	045
42216217	350 8 2 0 0 0 0 0 0	0002000000000020013116	0033325	2 3 8 4	045
43230236	50 7 0 3 0 0 0 0 0	0000001000000030014015	3032239	3 917 8	230
44230236	150 6 0 4 0 0 0 0 0	0002000100000011014015	0032239	21316 4	130
45236237	50 8 1 1 0 0 0 0 0	0002000200000000014015	0032238	21313 4	030
46236237	150 5 0 5 0 0 0 0 0	0000000200000010214012	0032238	2 8 6 2	030
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48237259	150 0 5 0 0 5 0 0 0	0010010300000000014014	0017642	22118 3	130
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50708709	150 9 1 0 0 0 0 0 0	0000010100000000013113	0032235	2 6 8 5	032
51 62078	50 1 9 0 0 0 0 0 0	0001000100000010015016	4035528	42428 5	138
52 62078	150 0 8 0 1 1 0 0 0	0001000100000021015016	5035528	22531 9	038
53 79091	50 0 8 0 0 2 0 0 0	000300020000000001601815135532		23030 4	138
54 79091	150 0 9 1 0 0 0 0 0	010000020001000001601812119942123740		7	138
55 79091	250 0 5 3 0 2 0 0 0	0001000100000000016018	0135528	1182822	218
57 79091	450 6 0 1 3 0 0 0 0	0002000100000011021601813135530		23040 7	138
58 79091	55010 0 0 0 0 0 0 0	000100010000001001511817133329		1 7 9 6	238
59 91124	50 1 4 5 0 0 0 0 0	0010000100000021014015	7017749	21518 3	032
60 91124	150 5 5 0 0 0 0 0 0	0001000100000010014010	0133345	31414 3	032
61 91124	250 5 4 1 0 0 0 0 0	000110000000000011401013033348		2 4 5 1	032
62124125	5010 0 0 0 0 0 0 0	0001000110000000014013	7334446	22624 7	034
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75235238	25010 0 0 0 0 0 0 0	0001001100000100014012	1033338	31718 5	035
77235238	45010 0 0 0 0 0 0 0	0000000000000000014012	0032243	1 2 7 2	035
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86266267	250 0 8 0 0 2 0 0 0	0000000200000100012213	4034434	21918 5	026
87267704	150 5 0 0 0 5 0 0 0	0002000000000010012213	0033343	1 916 3	126
88267704	250 5 0 3 0 0 0 1 1	0000000200000000212213	0033342	22012 4	326
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159 91093  50 8 0 0 0 0 2 0 0 000000100000000020012010 9134433 3 211 2 023
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171 20046  50 0 3 3 0 2 2 0 0 0000000110000000200120 9252355502213 6 1 016
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173 43046  5010 0 0 0 0 0 0 0 0000000100000060000201022233339 2 3 2 2 013
174 43046 150 9 0 0 0 1 0 0 0 0002000000000021000201232433341 5 4 2 2 013
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177 26027 250 5 0 0 0 0 0 5 0 0001000000000002300120 9 3332238 2 2 3 1 019
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226167169	350 1 0 9 0 0 0 0 0	00000001000000040012014	0233330 113 6 1 026
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234287298	50 0 2 3 0 5 0 0 0	0002010000010000001401510035532	1 9 4 4 230
235287298	150 0 5 3 0 0 0 2 0	00020000100000000014014	0035534 22536 6 030
236287298	250 0 4 5 0 0 0 1 0	00120000000000000014015	4117751181421 5 030
237303754	50 2 0 5 0 0 0 0 3	000100010000000000120	9 0034433 3 6 3 0 023
238275703	150 0 1 7 0 0 2 0 0	00000000000000000012013	0034437 3 0 0 0 021
239275703	250 3 0 4 0 0 0 3 0	00120002000000020012013	3117737 312 5 1 021
240275703	350 3 0 4 0 0 0 3 0	00101001100000000012014	0118838 21415 5 021
241275703	45010 0 0 0 0 0 0 0	00000000000000000012014	0034437 3 2 2 1 021
242275703	550 6 1 2 0 0 0 1 0	00020002000000010012012	0034436 2 5 5 0 021
243261262	50 0 0 0 5 0 3 2 0	00020000000000010012011	0033351 7 5 2 1 026
245255259	150 5 0 0 0 0 0 5 0	000100000000000001401135034433	2 7 2 0 029
246255259	250 1 0 0 0 2 2 5 0	0000000000000001001401225034432	4 4 2 1 029
247255259	350 2 1 0 0 7 0 0 0	0010010010000001001401251018825	31115 4 029
248253255	50 3 0 3 4 0 0 0 0	00000001000000010003010	0034436 3 4 3 1 024
249155742	5010 0 0 0 0 0 0 0	00020000000000321012010	0132231 2 4 2 1 018
250155742	15010 0 0 0 0 0 0 0	00000000000000700012010	0132240 2 3 1 0 018
251155742	25010 0 0 0 0 0 0 0	00020000000000801012010	0232240 1 1 3 1 018
252155742	35010 0 0 0 0 0 0 0	00000000000000601012010	0432240 2 4 2 0 018
253233249	50 5 5 0 0 0 0 0 0	00010001000000000012011	0034425 214 8 3 026
254233249	150 9 1 0 0 0 0 0 0	00100112000000000120111801874121	9 8 1 026
255228233	50 7 0 0 0 3 0 0 0	00000000000000000012011	4033327 2 6 5 1 024
256228233	15010 0 0 0 0 0 0 0	00000000000000000012011	2033323 11017 5 024
257228233	250 6 4 0 0 0 0 0 0	00110100000100000012012	3017730 62733 7 124
258228233	350 5 5 0 0 0 0 0 0	00010001000000000012010	1034426 12425 9 124
259191217	50 3 3 4 0 0 0 0 0	00000111000000000012010	7134440 21419 5 117
260191217	150 0 7 3 0 0 0 0 0	000002010001000100120	9 5135541 319 9 0 017
261191217	250 6 2 2 0 0 0 0 0	00120001000000040012010	111884614 7 4 1 017
262191217	350 2 8 0 0 0 0 0 0	00100100000100000012010	2118850162634 8 017
263191217	450 8 2 0 0 0 0 0 0	00010011000000020012111	0134430 213 7 2 017
264191217	55010 0 0 0 0 0 0 0	00000002000000010012111	0134430 12015 6 017
265191217	65010 0 0 0 0 0 0 0	00010000000000030012112	0033330 112 6 2 017
266191652	50 6 0 4 0 0 0 0 0	000200000000000100020	9 0034438 2 8 1 1 0 9
267191192	50 4 4 2 0 0 0 0 0	00011001000000000102011	0034433 6 9 5 1 0 9
268158159	50 5 0 0 0 0 0 5 0	00000001000000020014014	0234439 21314 3 029
269131158	50 5 0 0 0 0 0 5 0	00020002000000000014011	0034437 21227 7 135
270131158	150 5 0 0 0 0 0 5 0	00000001000000010014011	0134437 1 814 8 035
271131158	250 5 0 0 0 0 0 5 0	00000001000000030014011	0134437 11619 1 035
272131158	350 5 0 0 0 0 0 5 0	00010002000000040014013	2134438 11112 4 035
274721722	5010 0 0 0 0 0 0 0	000100010000003000120	812132238 3 1 4 4 010
275721722	15010 0 0 0 0 0 0 0	000200000000000000120	810032242 3 3 2 0 010
276721722	25010 0 0 0 0 0 0 0	000000000000003000120	8 7132242 3 2 1 0 010
277721722	35010 0 0 0 0 0 0 0	000000000000003100120	815132244 1 3 1 1 110
278721722	45010 0 0 0 0 0 0 0	000000000000002100120	819032244 1 1 1 1 010
279719721	5010 0 0 0 0 0 0 0	000000000000000000120	8 0132239 2 0 2 0 010
280719721	150 9 0 1 0 0 0 0 0	000110010000000002120	8 4133336 4 4 5 2 010
281719721	25010 0 0 0 0 0 0 0	000000010000000000120	822333340 2 3 0 0 010
282719721	35010 0 0 0 0 0 0 0	000000010000000000120	814233340 1 2 0 0 010
283 20757	50 4 0 4 0 0 2 0 0	0000000000000005001201011433332	2 3 3 1 017
284 20757	150 9 0 0 0 0 0 0 1	00000000000000300012010	6334434 3 4 1 0 017
285 20757	250 8 0 0 0 0 0 0 2	0002000000001000001201024134432	51413 7 417

Table D.2 Linear correlation arrays

- - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - -

(COEFFICIENT / (CASES) / SIGNIFICANCE)

	TOTACC	WETACC	WETSKD	ACCRAT	WETRAT	PCWET	PCSKID	XSWET	TRAFF
HOUSNG	-0.3214 (268) P=0.000	-0.1927 (268) P=0.001	-0.1135 (268) P=0.032	-0.2095 (268) P=0.000	-0.0713 (268) P=0.122	0.0473 (268) P=0.221	-0.1102 (268) P=0.036	0.1078 (268) P=0.039	-0.3720 (268) P=0.000
SHOPS	0.4937 (268) P=0.000	0.3060 (268) P=0.000	0.0792 (268) P=0.098	0.3797 (268) P=0.000	0.1761 (268) P=0.002	-0.0957 (268) P=0.059	0.0219 (268) P=0.360	-0.1505 (268) P=0.007	0.2680 (268) P=0.000
COMM	0.0478 (268) P=0.218	0.0203 (268) P=0.370	-0.0047 (268) P=0.469	0.0235 (268) P=0.351	-0.0166 (268) P=0.394	-0.0233 (268) P=0.352	0.0013 (268) P=0.492	-0.0284 (268) P=0.322	0.1570 (268) P=0.005
INDUST	0.0398 (268) P=0.258	-0.0187 (268) P=0.380	-0.0302 (268) P=0.311	-0.0055 (268) P=0.464	-0.0437 (268) P=0.238	-0.0240 (268) P=0.348	0.0017 (268) P=0.489	-0.0768 (268) P=0.105	0.0603 (268) P=0.163
PUBLBG	0.0690 (268) P=0.130	0.0369 (268) P=0.274	0.0645 (268) P=0.146	0.0150 (268) P=0.403	0.0025 (268) P=0.483	0.0246 (268) P=0.344	0.0736 (268) P=0.115	-0.0298 (268) P=0.314	0.2192 (268) P=0.000
SCHOOL	-0.1013 (268) P=0.049	-0.1123 (268) P=0.033	-0.0384 (268) P=0.266	-0.0653 (268) P=0.144	-0.0837 (268) P=0.086	-0.0407 (268) P=0.253	-0.0193 (268) P=0.377	-0.0428 (268) P=0.242	-0.0892 (268) P=0.073
OPENSP	-0.0985 (268) P=0.054	-0.0426 (268) P=0.244	0.0570 (268) P=0.176	-0.1206 (268) P=0.024	-0.0640 (268) P=0.148	0.0589 (268) P=0.168	0.1038 (268) P=0.045	0.0575 (268) P=0.174	0.0872 (268) P=0.077
VACANT	0.0393 (268) P=0.261	0.0546 (268) P=0.187	0.1022 (268) P=0.047	0.1067 (268) P=0.041	0.1224 (268) P=0.023	-0.0075 (268) P=0.451	0.0481 (268) P=0.216	0.0330 (268) P=0.295	-0.0710 (268) P=0.123
OTHER	0.0853 (268) P=0.082	0.1054 (268) P=0.042	0.1020 (268) P=0.048	0.0576 (268) P=0.174	0.0475 (268) P=0.219	0.0204 (268) P=0.369	0.1342 (268) P=0.014	0.0523 (268) P=0.197	0.0723 (268) P=0.119

Table D.2 (continued)

- - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - -

(COEFFICIENT / (CASES) / SIGNIFICANCE)

	HOUSNG	SHOPS	COMM	INDUST	PUBLBG	SCHOOL	OPENSP	VACANT	OTHER
HOUSNG	1.0000 (268) P=0.0	-0.5374 (268) P=0.000	-0.4514 (268) P=0.000	-0.2027 (268) P=0.000	-0.3032 (268) P=0.000	-0.0986 (268) P=0.054	-0.3585 (268) P=0.000	-0.1516 (268) P=0.006	-0.1159 (268) P=0.029
SHOPS	-0.5374 (268) P=0.000	1.0000 (268) P=0.0	-0.0267 (268) P=0.331	0.0558 (268) P=0.181	0.0190 (268) P=0.378	-0.1151 (268) P=0.030	-0.2078 (268) P=0.000	-0.0126 (268) P=0.419	0.1216 (268) P=0.023
COMM	-0.4514 (268) P=0.000	-0.0267 (268) P=0.331	1.0000 (268) P=0.0	0.0547 (268) P=0.186	-0.0373 (268) P=0.272	-0.0304 (268) P=0.310	-0.1125 (268) P=0.033	0.0815 (268) P=0.092	0.0195 (268) P=0.375
INDUST	-0.2027 (268) P=0.000	0.0558 (268) P=0.181	0.0547 (268) P=0.186	1.0000 (268) P=0.0	-0.0281 (268) P=0.323	0.0539 (268) P=0.190	-0.0740 (268) P=0.114	-0.0442 (268) P=0.236	-0.0187 (268) P=0.381
PUBLBG	-0.3032 (268) P=0.000	0.0190 (268) P=0.378	-0.0373 (268) P=0.272	-0.0281 (268) P=0.323	1.0000 (268) P=0.0	-0.0021 (268) P=0.486	-0.0197 (268) P=0.374	0.0411 (268) P=0.251	-0.0337 (268) P=0.291
SCHOOL	-0.0986 (268) P=0.054	-0.1151 (268) P=0.030	-0.0304 (268) P=0.310	0.0539 (268) P=0.190	-0.0021 (268) P=0.486	1.0000 (268) P=0.0	-0.0055 (268) P=0.464	-0.0307 (268) P=0.309	-0.0193 (268) P=0.374
OPENSP	-0.3585 (268) P=0.000	-0.2078 (268) P=0.000	-0.1125 (268) P=0.033	-0.0740 (268) P=0.114	-0.0197 (268) P=0.374	-0.0055 (268) P=0.464	1.0000 (268) P=0.0	-0.0811 (268) P=0.093	0.0134 (268) P=0.414
VACANT	-0.1516 (268) P=0.006	-0.0126 (268) P=0.419	0.0815 (268) P=0.092	-0.0442 (268) P=0.236	0.0411 (268) P=0.251	-0.0307 (268) P=0.309	-0.0811 (268) P=0.093	1.0000 (268) P=0.0	-0.0160 (268) P=0.397
OTHER	-0.1159 (268) P=0.029	0.1216 (268) P=0.023	0.0195 (268) P=0.375	-0.0187 (268) P=0.381	-0.0337 (268) P=0.291	-0.0198 (268) P=0.374	0.0134 (268) P=0.414	-0.0160 (268) P=0.397	1.0000 (268) P=0.0

Table D.2 (continued)

- - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - -

(COEFFICIENT / (CASES) / SIGNIFICANCE)

	TOTACC	WETACC	WETSKD	ACCRAT	WETRAT	PCWET	PCSKID	XSWET	TRAFF
PELICN	0.1437 (268) P=0.009	0.0875 (268) P=0.076	0.0123 (268) P=0.421	0.0651 (268) P=0.144	0.0209 (268) P=0.367	-0.0122 (268) P=0.421	-0.0162 (268) P=0.396	-0.0461 (268) P=0.226	0.1541 (268) P=0.006
ZEBRA	0.1902 (268) P=0.001	0.0507 (268) P=0.204	-0.0341 (268) P=0.289	0.1988 (268) P=0.001	0.0332 (268) P=0.294	-0.0825 (268) P=0.089	0.0371 (268) P=0.273	-0.1580 (268) P=0.005	0.0455 (268) P=0.229
BUSSTP	0.1907 (268) P=0.001	0.0953 (268) P=0.060	0.1106 (268) P=0.035	0.1116 (268) P=0.034	0.0602 (268) P=0.163	0.0804 (268) P=0.095	0.0601 (268) P=0.164	-0.0922 (268) P=0.066	0.1439 (268) P=0.009
GARAGE	0.0213 (268) P=0.365	0.0272 (268) P=0.329	-0.0076 (268) P=0.451	0.0144 (268) P=0.407	0.0171 (268) P=0.390	0.0907 (268) P=0.069	0.0112 (268) P=0.428	0.0144 (268) P=0.407	0.0621 (268) P=0.156
PUB	0.0675 (268) P=0.135	0.0685 (268) P=0.132	0.0180 (268) P=0.385	0.1194 (268) P=0.025	0.0623 (268) P=0.155	0.0198 (268) P=0.373	-0.0105 (268) P=0.432	0.0191 (268) P=0.378	-0.0255 (268) P=0.339
JCT	0.2687 (268) P=0.000	0.1811 (268) P=0.001	0.0920 (268) P=0.066	0.2415 (268) P=0.000	0.1413 (268) P=0.010	-0.0113 (268) P=0.427	0.0736 (268) P=0.115	-0.0601 (268) P=0.163	0.1063 (268) P=0.041
ACCESS	-0.2250 (268) P=0.000	-0.1787 (268) P=0.002	-0.0674 (268) P=0.136	-0.1950 (268) P=0.001	-0.1179 (268) P=0.027	0.0728 (268) P=0.118	-0.0052 (268) P=0.466	0.0102 (268) P=0.434	-0.1501 (268) P=0.007
BUSL	0.0906 (268) P=0.070	0.0863 (268) P=0.079	0.1411 (268) P=0.010	0.0161 (268) P=0.397	0.0076 (268) P=0.451	0.0571 (268) P=0.176	0.0668 (268) P=0.138	0.0173 (268) P=0.389	0.3111 (268) P=0.000
BEND	-0.1079 (268) P=0.039	-0.0997 (268) P=0.052	0.0420 (268) P=0.247	-0.0791 (268) P=0.098	-0.0661 (268) P=0.140	0.0530 (268) P=0.194	0.0878 (268) P=0.076	-0.0161 (268) P=0.397	-0.2051 (268) P=0.000
GRAD	-0.1633 (268) P=0.004	-0.0610 (268) P=0.160	-0.0535 (268) P=0.191	-0.0930 (268) P=0.064	0.0321 (268) P=0.300	0.0739 (268) P=0.114	-0.0349 (268) P=0.285	0.1096 (268) P=0.037	-0.2387 (268) P=0.000
WIDTH	0.4032 (268) P=0.000	0.2918 (268) P=0.000	0.1722 (268) P=0.002	0.1639 (268) P=0.004	0.0954 (268) P=0.060	0.0208 (268) P=0.367	0.0380 (268) P=0.268	-0.0606 (268) P=0.162	0.6589 (268) P=0.000
WDEF	-0.1425 (268) P=0.010	-0.1280 (268) P=0.018	-0.0977 (268) P=0.055	-0.1427 (268) P=0.010	-0.1530 (268) P=0.006	-0.0323 (268) P=0.300	0.0054 (268) P=0.465	-0.0157 (268) P=0.399	-0.0000 (268) P=0.500

Table D.2 (continued)

- - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - -

(COEFFICIENT / (CASES) / SIGNIFICANCE)

	TOTACC	WETACC	WETSKD	ACCRAT	WETRAT	PCWET	PCSKID	XSWET	TRAFF
JCT	0.2687 (268) P=0.000	0.1811 (268) P=0.001	0.0920 (268) P=0.066	0.2415 (268) P=0.000	0.1413 (268) P=0.010	-0.0113 (268) P=0.427	0.0736 (268) P=0.115	-0.0601 (268) P=0.163	0.1063 (268) P=0.041
TJCT	0.2546 (268) P=0.000	0.1861 (268) P=0.001	0.0765 (268) P=0.106	0.2298 (268) P=0.000	0.1389 (268) P=0.011	-0.0508 (268) P=0.204	0.0457 (268) P=0.228	-0.0355 (268) P=0.281	0.0891 (268) P=0.073
TJCT1	0.0285 (268) P=0.321	-0.0232 (268) P=0.352	-0.0065 (268) P=0.458	0.0443 (268) P=0.235	-0.0233 (268) P=0.352	-0.0636 (268) P=0.150	0.0018 (268) P=0.489	-0.0697 (268) P=0.128	-0.0019 (268) P=0.488
TJCT2	0.2367 (268) P=0.000	0.1826 (268) P=0.001	0.0799 (268) P=0.096	0.2125 (268) P=0.000	0.1442 (268) P=0.009	-0.0346 (268) P=0.286	0.0463 (268) P=0.225	-0.0187 (268) P=0.380	0.0704 (268) P=0.125
TJCT3	0.0979 (268) P=0.055	0.0942 (268) P=0.062	0.0116 (268) P=0.425	0.0652 (268) P=0.144	0.0424 (268) P=0.245	0.0104 (268) P=0.433	0.0049 (268) P=0.468	0.0200 (268) P=0.372	0.1105 (268) P=0.035
XRD	0.0800 (268) P=0.096	0.1096 (268) P=0.037	0.0880 (268) P=0.075	0.1706 (268) P=0.003	0.1644 (268) P=0.004	0.1038 (268) P=0.045	0.0879 (268) P=0.076	0.0650 (268) P=0.144	-0.1040 (268) P=0.045
XRD1	-0.0367 (268) P=0.275	-0.0551 (268) P=0.185	-0.0273 (268) P=0.328	-0.0099 (268) P=0.436	-0.0513 (268) P=0.202	-0.0636 (268) P=0.150	-0.0237 (268) P=0.349	-0.0370 (268) P=0.273	-0.0853 (268) P=0.082
XRD2	0.0734 (268) P=0.116	0.0456 (268) P=0.228	0.1104 (268) P=0.036	0.1046 (268) P=0.044	0.0416 (268) P=0.249	-0.0022 (268) P=0.486	0.1616 (268) P=0.004	-0.0222 (268) P=0.359	-0.0490 (268) P=0.212
XRD3	0.0289 (268) P=0.319	0.1267 (268) P=0.019	0.0847 (268) P=0.083	0.0856 (268) P=0.081	0.1940 (268) P=0.001	0.1337 (268) P=0.014	0.0027 (268) P=0.482	0.1532 (268) P=0.006	-0.0369 (268) P=0.274
XRD4	0.0577 (268) P=0.173	0.0738 (268) P=0.114	-0.0448 (268) P=0.233	0.1510 (268) P=0.007	0.1356 (268) P=0.013	0.1309 (268) P=0.016	-0.0389 (268) P=0.263	0.0391 (268) P=0.262	-0.0942 (268) P=0.062

Table D.2 (continued)

- - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - -

(COEFFICIENT / (CASES) / SIGNIFICANCE)

	(SFC)	$(SFC)^{-1}$	$(SFC)^{2}$	$(SFC)^{-2}$	log(SFC)	$\log(SFC)^{-1}$	$(SFC)^{1/2}$	$(SFC)^{-1/2}$
TOTACC	-0.1142 (238) P=0.039	0.1476 (238) P=0.011	-0.0949 (238) P=0.072	0.1601 (238) P=0.007	-0.1321 (238) P=0.021	0.1411 (238) P=0.015	-0.1234 (238) P=0.029	0.1402 (238) P=0.015
WETACC	-0.2009 (238) P=0.001	0.2356 (238) P=0.000	-0.1791 (238) P=0.003	0.2467 (238) P=0.000	-0.2200 (238) P=0.000	0.2292 (238) P=0.000	-0.2109 (238) P=0.001	0.2283 (238) P=0.000
WETSKD	-0.0853 (238) P=0.095	0.0857 (238) P=0.094	-0.0825 (238) P=0.102	0.0826 (238) P=0.102	-0.0865 (238) P=0.092	0.0862 (238) P=0.092	-0.0861 (238) P=0.093	0.0864 (238) P=0.092
ACCRAT	-0.0749 (238) P=0.125	0.0934 (238) P=0.075	-0.0656 (238) P=0.157	0.1016 (238) P=0.059	-0.0843 (238) P=0.097	0.0895 (238) P=0.084	-0.0796 (238) P=0.111	0.0889 (238) P=0.086
WETRAT	-0.1674 (238) P=0.005	0.1874 (238) P=0.002	-0.1547 (238) P=0.008	0.1934 (238) P=0.001	-0.1785 (238) P=0.003	0.1838 (238) P=0.002	-0.1732 (238) P=0.004	0.1833 (238) P=0.002
SKRAT	-0.0588 (238) P=0.183	0.0584 (238) P=0.185	-0.0574 (238) P=0.189	0.0561 (238) P=0.194	-0.0592 (238) P=0.182	0.0589 (238) P=0.183	-0.0591 (238) P=0.182	0.0590 (238) P=0.182
XSWET	-0.1816 (238) P=0.002	0.1970 (238) P=0.001	-0.1700 (238) P=0.004	0.1999 (238) P=0.001	-0.1908 (238) P=0.002	0.1946 (238) P=0.001	-0.1865 (238) P=0.002	0.1943 (238) P=0.001
PCWET	-0.0893 (238) P=0.085	0.0966 (238) P=0.069	-0.0831 (238) P=0.101	0.0973 (238) P=0.067	-0.0939 (238) P=0.074	0.0956 (238) P=0.071	-0.0919 (238) P=0.079	0.0955 (238) P=0.071
PCSKID	0.0193 (238) P=0.383	-0.0266 (238) P=0.341	0.0154 (238) P=0.407	-0.0301 (238) P=0.322	0.0231 (238) P=0.362	-0.0251 (238) P=0.350	0.0212 (238) P=0.372	-0.0249 (238) P=0.351

Table D.2 (continued)

- - - - - - - - - - - - P E A R S O N   C O R R E L A T I O N   C O E F F I C I E N T S - - - - - - - - - - - -

(COEFFICIENT / (CASES) / SIGNIFICANCE)

	TOTACC	WETACC	WETSKD	ACCRAT	WETRAT	PCWET	PCSKID	XSWET	TRAFF
ACCESS	-0.2250 (268) P=0.000	-0.1787 (268) P=0.002	-0.0674 (268) P=0.136	-0.1950 (268) P=0.001	-0.1179 (268) P=0.027	0.0728 (268) P=0.118	-0.0052 (268) P=0.466	0.0102 (268) P=0.434	-0.1501 (268) P=0.007
MINACC	-0.2774 (268) P=0.000	-0.1980 (268) P=0.001	-0.0777 (268) P=0.103	-0.2207 (268) P=0.000	-0.1179 (268) P=0.027	0.0825 (268) P=0.089	-0.0126 (268) P=0.419	0.0457 (268) P=0.228	-0.2115 (268) P=0.000
MAJACC	0.0702 (268) P=0.126	-0.0024 (268) P=0.485	0.0069 (268) P=0.456	0.0094 (268) P=0.439	-0.0350 (268) P=0.284	-0.0038 (268) P=0.475	0.0178 (268) P=0.386	-0.0897 (268) P=0.072	0.1159 (268) P=0.029
ACCSS1	-0.2656 (268) P=0.000	-0.1790 (268) P=0.002	-0.0374 (268) P=0.271	-0.2301 (268) P=0.000	-0.1030 (268) P=0.046	0.0615 (268) P=0.158	0.0046 (268) P=0.470	0.0596 (268) P=0.166	-0.2575 (268) P=0.000
ACCSS2	-0.0715 (268) P=0.122	-0.0658 (268) P=0.142	-0.0712 (268) P=0.123	-0.0309 (268) P=0.307	-0.0441 (268) P=0.236	0.0454 (268) P=0.229	-0.0264 (268) P=0.334	-0.0102 (268) P=0.434	0.0216 (268) P=0.362
ACCSS3	0.1536 (268) P=0.006	-0.0017 (268) P=0.489	-0.0851 (268) P=0.082	0.0455 (268) P=0.229	-0.0634 (268) P=0.151	-0.1061 (268) P=0.041	-0.0762 (268) P=0.107	-0.1911 (268) P=0.001	0.1439 (268) P=0.009
ACCSS4	-0.0147 (268) P=0.405	-0.0017 (268) P=0.489	0.0607 (268) P=0.161	-0.0174 (268) P=0.388	-0.0008 (268) P=0.494	0.0615 (268) P=0.158	0.0677 (268) P=0.135	0.0155 (268) P=0.400	0.0439 (268) P=0.237

Table D.3 Regression summaries

* * * * * * * M U L T I P L E R E G R E S S I O N * * * * * * * *

SUMMARY LIST 1 ALL VARIABLES EXCEPT SFC

DEPENDENT VARIABLE..... TOTACC NO OF CASES.. 268

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B (COEFFICIENT)
SHOPS	0.49368	0.24372	0.24372	0.49368	1.212768
TRAFF	0.59329	0.35199	0.10827	0.44929	0.242489
TJCT	0.60711	0.36858	0.01659	0.25462	1.434697
WIDTH	0.61965	0.38397	0.01538	0.40320	0.463897
ONEWAY	0.62787	0.39422	0.01025	0.15170	3.920430
XRD	0.63491	0.40312	0.00889	0.07996	2.901948
BUSSTP	0.64233	0.41259	0.00947	0.19068	0.948519
PEDX	0.64609	0.41743	0.00485	0.22885	2.575797
MINACC	0.64766	0.41947	0.00204	-0.27737	-0.386345
MAJACC	0.64928	0.42156	0.00210	0.07015	0.847254
HOUSNG	0.65092	0.42370	0.00214	-0.32143	0.013527
BEND	0.65242	0.42565	0.00195	-0.10787	-0.049154
PUB	0.65369	0.42731	0.00166	0.06753	-1.296944
BUSL	0.65456	0.42845	0.00114	0.09056	0.862931
COMM	0.65492	0.42893	0.00048	0.04780	-0.220218
OPENSP	0.65527	0.42937	0.00045	-0.09847	-0.152015
GRAD	0.65550	0.42968	0.00031	-0.16331	0.118904
(CONSTANT)					-8.482586

(GARAGE REJECTED FROM REGRESSION)

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* * * * * * * * * M U L T I P L E R E G R E S S I O N * * * * * * *

SUMMARY LIST 2 ALL VARIABLES EXCEPT SFC

DEPENDENT VARIABLE..... WETACC NO OF CASES.. 268

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B (COEFFICIENT)
SHOPS	0.30597	0.09362	0.09362	0.30597	0.265932
WIDTH	0.38086	0.14506	0.05144	0.29175	0.172313
ONEWAY	0.40376	0.16303	0.01797	0.14933	1.354057
TJCT	0.42119	0.17740	0.01437	0.18605	0.424571
XRD	0.43584	0.18995	0.01256	0.10959	1.080963
TRAFF	0.44375	0.19691	0.00696	0.29667	0.036225
GRAD	0.44809	0.20079	0.00387	-0.06103	0.132052
BEND	0.45151	0.20386	0.00307	-0.09973	-0.018327
MINACC	0.45419	0.20629	0.00244	-0.19800	-0.086470
COMM	0.45612	0.20804	0.00175	0.02035	-0.037020
GARAGE	0.45768	0.20947	0.00143	0.02721	0.496086
PEDX	0.45884	0.21053	0.00106	0.07699	-0.295705
BUSSTP	0.45979	0.21141	0.00087	0.09532	0.115840
MAJACC	0.46027	0.21185	0.00044	-0.00238	-0.106911
PUB	0.46046	0.21202	0.00017	0.06852	0.148586
HOUSNG	0.46064	0.21219	0.00016	-0.19265	0.038909
OPENSP	0.46099	0.21251	0.00032	-0.04256	0.038422
(CONSTANT)					-2.608500

(BUSL REJECTED FROM REGRESSION)

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Table D.3 (continued)

* * * * * * * M U L T I P L E   R E G R E S S I O N * * * * * * * *

SUMMARY LIST 3   ALL VARIABLES EXCEPT SFC

DEPENDENT VARIABLE..... WETSKD   NO OF CASES.. 268

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B (COEFFICIENT)
WIDTH	0.17215	0.02964	0.02964	0.17215	0.0190090
BUSL	0.19838	0.03936	0.00972	0.14110	0.1566478
XRD	0.22158	0.04910	0.00974	0.08797	0.1967954
BUSSTP	0.24085	0.05801	0.00891	0.11055	0.0653464
ONEWAY	0.25330	0.06416	0.00615	0.10090	0.2744321
TJCT	0.26462	0.07003	0.00586	0.07652	0.0695628
OPENSP	0.27692	0.07668	0.00666	0.05702	0.0124239
BEND	0.28707	0.08241	0.00572	0.04200	0.0048422
PEDX	0.29440	0.08667	0.00426	-0.02868	-0.1577134
SHOPS	0.29934	0.08961	0.00294	0.07924	-0.0010985
COMM	0.30037	0.09022	0.00062	-0.00474	-0.0217934
HOUSNG	0.30308	0.09186	0.00164	-0.11348	-0.0147514
MINACC	0.30369	0.09223	0.00037	-0.07766	0.0079021
TRAFF	0.30395	0.09239	0.00016	0.14971	0.0013862
PUB	0.30421	0.09254	0.00016	0.01797	0.0233047
GARAGE	0.30438	0.09265	0.00011	-0.00756	-0.0220490
(CONSTANT)					-0.3219862

(MAJACC AND GRAD REJECTED FROM REGRESSION)

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Table D.3 (continued)

* * * * * * * * M U L T I P L E   R E G R E S S I O N * * * * * * *

SUMMARY LIST 4   ALL VARIABLES

DEPENDENT VARIABLE......TOTACC   NO OF CASES.. 238

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B (COEFFICIENT)
TRAFF	0.45271	0.20494	0.20494	0.45271	0.269070
SHOPS	0.55471	0.30770	0.10276	0.42997	0.838246
TJCT	0.58179	0.33848	0.03078	0.30447	1.721602
BUSSTP	0.59052	0.34871	0.01024	0.16657	0.937401
ONEWAY	0.59847	0.35817	0.00946	0.14229	3.578934
XRD	0.60125	0.36150	0.00333	0.00324	1.442995
WIDTH	0.60336	0.36404	0.00254	0.33974	0.231878
PUB	0.60506	0.36610	0.00206	0.00833	-1.368568
MINACC	0.60686	0.36828	0.00218	-0.23715	-0.302142
SFC	0.60775	0.36936	0.00108	-0.11423	-0.076000
GARAGE	0.60863	0.37043	0.00107	0.06813	1.481496
BEND	0.60932	0.37126	0.00084	-0.08785	-0.034718
OPENSP	0.60963	0.37164	0.00038	-0.06969	-0.242372
COMM	0.60991	0.37199	0.00035	0.07733	-0.237475
HOUSNG	0.61048	0.37269	0.00070	-0.30532	-0.150315
BUSL	0.61074	0.37300	0.00031	0.13620	-0.346812
MAJACC	0.61094	0.37325	0.00024	0.04447	-0.268899
PEDX	0.61104	0.37337	0.00012	0.12485	0.418027
GRAD	0.61111	0.37346	0.00009	-0.16427	0.058616
(CONSTANT)					-2.170611

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SUMMARY LIST 5   ALL VARIABLES

DEPENDENT VARIABLE......WETACC   NO OF CASES.. 238

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B (COEFFICIENT)
TRAFF	0.31835	0.10135	0.10135	0.31835	0.043100
SHOPS	0.38144	0.14550	0.04415	0.28762	0.224332
SFC	0.40997	0.16808	0.02258	-0.20091	-0.100768
TJCT	0.42485	0.18050	0.01242	0.19935	0.422024
WIDTH	0.44049	0.19403	0.01354	0.28312	0.185877
ONEWAY	0.44961	0.20215	0.00812	0.13704	1.038039
GRAD	0.45848	0.21020	0.00806	-0.04547	0.188401
MINACC	0.46435	0.21562	0.00542	-0.17618	-0.114107
XRD	0.46825	0.21926	0.00364	0.04959	0.645774
BEND	0.47275	0.22349	0.00423	-0.07750	-0.022458
PEDX	0.47620	0.22677	0.00327	0.01828	-0.589879
COMM	0.47768	0.22817	0.00141	0.02582	-0.069148
GARAGE	0.47937	0.22979	0.00162	0.04616	0.766750
MAJACC	0.48135	0.23170	0.00190	-0.01467	-0.268398
BUSSTP	0.48289	0.23318	0.00148	0.09454	0.124796
BUSL	0.48349	0.23376	0.00058	0.09179	-0.183163
OPENSP	0.48354	0.23381	0.00005	-0.01990	0.010301
(CONSTANT)					1.477931

(PUB AND HOUSNG REJECTED FROM REGRESSION)

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Table D.3 (continued)

* * * * * * * * M U L T I P L E R E G R E S S I O N * * * * * * * *

SUMMARY LIST 6 ALL VARIABLES

DEPENDENT VARIABLE......WETSKD NO OF CASES.. 238

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B (COEFFICIENT)
WIDTH	0.21001	0.04411	0.04411	0.21001	0.025284
HOUSNG	0.23149	0.05359	0.00948	-0.15868	-0.033202
COMM	0.25116	0.06308	0.00949	0.00733	-0.035333
XRD	0.26736	0.07148	0.00840	0.08170	0.181682
ONEWAY	0.27926	0.07799	0.00650	0.09930	0.255155
BUSL	0.29053	0.08441	0.00642	0.13179	0.127148
BUSSTP	0.30399	0.09241	0.00800	0.13318	0.066295
SFC	0.30952	0.09580	0.00340	-0.08527	-0.006531
SHOPS	0.31273	0.09780	0.00199	0.08455	-0.019450
TJCT	0.31709	0.10055	0.00275	0.04440	0.045598
BEND	0.32037	0.10264	0.00209	0.04114	0.003750
MINACC	0.32195	0.10365	0.00101	-0.06990	0.011424
GARAGE	0.32372	0.10479	0.00114	-0.02303	-0.091361
TRAFF	0.32526	0.10580	0.00100	0.18357	0.003126
PEDX	0.32657	0.10665	0.00085	-0.00484	-0.069510
GRAD	0.32718	0.10705	0.00040	-0.05490	0.008515
MAJACC	0.32736	0.10716	0.00011	0.00938	0.012598
PUB	0.32747	0.10724	0.00007	0.02439	0.018210
(CONSTANT)					0.007668

(OPENSP REJECTED FROM REGRESSION)

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SUMMARY LIST 7 ALL VARIABLES

DEPENDENT VARIABLE......XSWET NO OF CASES.. 238

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B (COEFFICIENT)
SFC	0.18160	0.03298	0.03298	-0.18160	-0.109180
GRAD	0.22335	0.04989	0.01691	0.11979	0.231736
PEDX	0.24768	0.06135	0.01146	-0.11651	-0.932841
WIDTH	0.26134	0.06830	0.00695	0.04812	0.170735
TRAFF	0.27338	0.07474	0.00644	-0.02807	-0.032124
MAJACC	0.28307	0.08013	0.00539	-0.07465	-0.268308
XRD	0.28881	0.08341	0.00328	0.07382	0.368883
BEND	0.29632	0.08781	0.00440	-0.01917	-0.018098
OPENSP	0.30110	0.09066	0.00285	0.04987	0.106490
BUSSTP	0.30581	0.09352	0.00286	-0.04569	-0.142962
PUB	0.31003	0.09612	0.00260	0.03401	0.521107
HOUSNG	0.31429	0.09878	0.00266	0.05266	0.061468
GARAGE	0.31846	0.10142	0.00264	-0.00695	0.529683
MINACC	0.32024	0.10256	0.00114	-0.00004	-0.504237
BUSL	0.32087	0.10296	0.00040	-0.01469	-0.122250
SHOPS	0.32134	0.10326	0.00030	-0.04972	0.028494
ONEWAY	0.32166	0.10347	0.00021	0.04904	0.185975
(CONSTANT)					2.577875

(TJCT AND COMM REJECTED FROM REGRESSION)

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APPENDIX E

DATA FROM STUDY OF RELATIONSHIP BETWEEN ACCIDENT RISK AND SFC (Chapter 7)

Table E.1 Coded site parameters for 237 links.

VARIABLE			COLUMNS
CASENO	-	Case number	1 - 3
BORO	-	Borough number	5 - 6
LINK	-	Link number	8 - 13
CLASS	-	Land use class	15 - 15
TRAFF	-	Total daily vehicle flow in thousands	17 - 18
TOT	-	Total number of accidents (in three years)	20 - 22
PED	-	Number of accidents involving pedestrians	24 - 26
WET	-	Number of wet-road accidents	28 - 30
ICE	-	Number of accidents on snow/ice	32 - 34
WETSKID	-	Number of wet-road skidding accidents	36 - 38
LENGTH	-	Link length (tens of metres)	40 - 42
SFC	-	Mean SFC (x100)	44 - 47
SFCDEV	-	Standard deviation of SFC	49 - 52

1	22	646647	1	37	2		1			12	37.5	2.9
2	22	078079	1	16	2					25	41.7	3.5
3	22	078605	1	16	1					22	41.2	2.5
4	22	066067	1	17	19	6	3			97	41.5	2.5
5	22	103104	2	23	8	1	1		1	50	38.1	4.6
6	22	016733	2	17	2		1			42	40.2	1.4
7	22	079081	2	32						24	43.2	3.8
8	22	706707	2	20	14	3	8		1	59	41.4	2.5
9	22	158159	3	37	18	6	5	1		14	35.8	3.2
10	22	160162	3	30	7		5			18	38.3	2.6
11	22	160638	3	36	1	1	1			13	36.2	3.8
12	22	113116	4	30	3	1				10	38.8	1.3
13	22	641642	4	29	5	2	1			21	42.5	2.1
14	22	070073	4	21	1		1			10	43.6	2.2
15	22	164638	4	30	10	2	3	1		26	35.2	2.3
16	22	164637	4	30	16	3	7		1	29	34.5	4.4
17	22	053059	5	31	11	1	6	1	1	97	36.1	2.8
18	22	059712	5	31	20	5	4	2	1	91	36.8	2.5
19	22	053056	5	22	1		1			32	41.8	1.7
20	22	043046	5	25						18	37.3	2.8
21	22	056732	6	21	20	3	8			72	38.4	3.6
22	21	031067	1	16	16	1	4			104	43.4	2.3
23	21	001712	1	26	14	1	4		1	86	46.7	2.3
24	21	001042	1	26	11	2	5	1	1	132	50.2	2.6
25	21	042663	2	27	36	8	8			136	45.8	2.6
26	21	707708	2	20	3	1	1			31	42.3	2.3
27	21	042043	2	25	7		1			49	43.7	2.7
28	21	097734	2	22	18	3	3	1		68	50.2	4.2
29	21	062063	4	23	20	7	8			34	41.1	3.6
30	21	004021	5	17	10	1	3	1		73	36.7	3.6
31	21	004718	5	18	10	1	4		1	55	39.0	3.0
32	21	021722	6	17	5		3	1	1	75	38.3	2.5
33	19	392399	1	7						21	34.9	3.6
34	19	392393	1	9	6	1	1			19	43.8	2.3
35	19	558692	1	18						30	47.6	2.5
36	19	558676	1	18	2					37	49.4	2.7
37	19	543676	1	18						12	46.9	2.7
38	19	543544	1	9						14	46.9	2.7
39	19	451728	1	13	15	4	2		1	99	43.5	2.4
40	19	256298	1	18	10	3	3		1	100	48.4	5.6
41	19	219222	1	21	15	3	1			70	44.1	4.4
42	19	196197	1	13						31	47.0	3.8
43	19	197198	1	13						13	45.7	3.6
44	19	533534	1	15	9	2	3	1		84	44.4	2.2
45	19	371376	1	18	3		2			38	45.1	3.0
46	19	467763	2	16	43	8	12	3	2	148	41.0	5.0
47	19	707720	2	15	29	12	8			118	40.6	4.5
48	19	249529	2	24	21	5	5	1		107	46.2	5.9

Table E.1 (continued)

49	19	534556	2	28	43	6	11			120	38.2	5.4
50	19	398402	2	28	29	5	8			109	43.2	4.4
51	19	376384	2	20	33	3	8		1	154	46.4	5.8
52	19	393399	3	11	1	1				20	33.4	2.4
53	19	552553	3	24	5	1				28	42.3	2.3
54	19	391417	4	23	1					20	44.7	3.5
55	19	372416	4	14	3					16	49.8	5.3
56	19	371372	4	9	1	1				13	43.6	4.8
57	19	413436	4	20	9	4	3		1	38	44.3	4.6
58	19	436449	4	21	56	28	17	1	3	87	38.1	3.8
59	19	368371	4	26	9	7	4			25	36.9	5.8
60	19	366367	4	26	7	3	1			19	44.9	2.8
61	19	479481	5	13	2	2	1			26	46.5	2.5
62	19	481482	5	13	5	2	1			27	41.8	2.9
63	19	093173	5	15	15		6	1	3	89	40.3	5.3
64	19	117191	5	24	2		1			80	42.8	2.6
65	19	191192	5	24	3					10	46.6	1.9
66	19	184192	5	24	6	1	2			73	46.2	2.4
67	19	152733	5	17	2					11	47.8	2.7
68	19	431572	6	18	6	1	2	1	1	100	49.2	5.2
69	19	173212	6	9	17	1	4	3		158	41.3	3.7
70	19	002708	6	9	1					38	46.0	1.7
71	19	117122	6	19	17	1	7		2	190	42.4	3.9
72	19	177184	6	25	13	1	4	1		88	43.2	2.7
73	19	243280	6	31	21	5	2		2	112	40.9	3.8
74	19	196738	6	18	8		2			110	44.5	2.8
75	19	152534	6	17	49	9	16	2	2	350	50.2	4.5
76	19	429482	6	18	4		2			66	38.9	3.0
77	29	718719	1	31	10	3	3	2		26	47.4	3.1
78	29	672719	1	31	5	4	1			29	47.8	3.2
79	29	105122	1	23	6	2	1		1	56	44.5	2.5
80	29	125648	1	23						26	54.0	3.8
81	29	074076	1	18	4	1	1			36	51.0	3.6
82	29	053664	1	20	3		2		1	37	37.1	3.5
83	29	673749	1	11	14	3	6		1	53	39.5	2.0
84	29	062067	1	11	2		2			32	48.4	3.1
85	29	073074	1	11	2			1		44	50.4	3.2
86	29	114179	1	12	24	4	10	1		121	43.8	3.6
87	29	034161	2	24	6	2	1	1		27	44.6	2.0
88	29	122702	2	29	35	13	7	1		118	44.2	5.9
89	29	019695	2	24	10	1	2			91	49.2	3.2
90	29	046695	2	24	4		1			25	45.5	2.6
91	29	019022	2	12	3					52	49.8	2.4
92	29	022742	2	26	18	1	7			93	48.0	5.6
93	29	053174	3	20	12	4	6		2	24	28.7	2.1
94	29	121179	3	15	10	5	4	1		23	39.7	4.2
95	29	038041	4	24	17	4	4			54	43.4	4.3
96	2	082646	1	19	1					19	37.8	1.9
97	2	048049	1	26						10	36.8	1.0
98	2	668742	1	13	3		1			17	29.1	1.1
99	2	051082	2	19	1					14	38.8	1.6
100	2	049051	2	16	4	1				13	37.6	1.4
101	2	116134	2	12	1					42	43.3	2.4
102	2	184207	2	54	20	8	4			41	39.6	3.6
103	2	156767	2	24	5	2	2			23	36.4	2.6
104	2	129667	3	20	12	7	2			22	52.0	5.8
105	2	137139	3	40	5	4	1			12	40.8	1.8
106	2	079081	3	29	6	5				10	40.5	1.2
107	2	643644	3	29	3		1			20	38.8	1.4
108	2	088644	3	29	12	7	2	1		16	38.2	1.9
109	2	111128	3	34	26	5	4			28	41.3	4.0
110	2	024027	3	32	6	1	1			11	34.3	3.5
111	2	173674	3	55	11	6	7	1		19	39.4	2.9

Table E.1 (continued)

112	2.153674	3	55	19	7	8			27	35.7	1.3
113	2.702721	4	28	18	4	13		1	28	33.4	5.2
114	2.162163	4	38	15	5	3			30	44.7	2.0
115	2.110801	4	18	1					16	49.2	1.7
116	2.666667	4	25	5	1	1			16	36.9	3.0
117	2.163666	4	40	20	4	4			26	37.4	2.8
118	2.167168	4	34	7	2	1			15	46.0	3.2
119	2.198199	4	34	2					11	48.3	1.1
120	2.198741	4	18	22	10	4			58	42.6	4.5
121	2.014713	4	24	14	6	6		1	23	35.4	3.0
122	2.702721	4	28	18	4	13		1	28	33.4	5.2
123	2.173184	4	55	62	29	20	2		55	37.4	2.9
124	2 216772	6	24	13	2	4	4		66	36.2	2.4
125	3.118674	1	12	5		2	1	1	53	42.9	4.2
126	3.654772	1	15	1					10	44.0	5.5
127	3.131674	2	19	7	1	4			64	41.9	3.1
128	3.670748	3	13	5	1	1			35	36.3	4.5
129	3.083086	3	28	18	12	3			31	41.6	3.6
130	3.707708	3	16						10	33.2	3.0
131	3 073212	4	17	31	15	4			60	37.4	5.6
132	3.749751	4	17	8	4				27	44.5	3.0
133	3.801802	4	37	5	1				10	33.8	1.1
134	3.150655	4	42	52	22	17		1	57	42.4	3.4
135	3.742743	4	13	3					23	38.2	3.3
136	3.731732	4	41	2	1				12	32.9	4.9
137	3.014016	4	28	3					23	38.1	3.0
138	3.013014	4	29	6	2		1		25	36.8	1.9
139	3 147708	4	16	8	5	2			28	33.9	2.2
140	31.702703	4	17	12	7	2			37	33.0	3.6
141	7 036763	1	16	10	1	6			42	40.0	2.7
142	7.010020	1	20	2					19	41.0	3.9
143	7.103106	1	33	19	3	5			46	34.6	5.8
144	7 213214	2	11	4	2	1			18	51.3	3.5
145	7 037118	2	18	35	3	9	1	1	168	42.2	3.7
146	7.006728	2	24	18	6	4			100	42.6	2.7
147	7.036037	3	29	3					10	32.4	1.8
148	7.194198	4	57	51	22	15			40	32.2	2.4
149	6.091180	1	15	27	5	7			94	47.1	3.3
150	6.002707	1	12	3	2				46	37.4	2.2
151	6 126706	2	15	6	2	2			44	43.9	5.1
152	6.126174	2	10	15	5	2	1		74	43.2	4.7
153	6.041736	2	17	10	2	7		1	43	33.8	1.8
154	6.026034	2	14	2		2			37	44.0	3.8
155	6 016026	2	21	11	1	4	1		50	28.9	4.5
156	6.002033	2	13	38	12	9	1		134	46.0	4.4
157	6.048049	2	27	19	6	4	1		77	36.8	2.6
158	6.134169	4	12	24	9	4			37	34.9	4.6
159	6.125713	5	31	7	4	2			39	38.1	3.0
160	6.088125	5	36	1		1			18	29.8	4.0
161	6 186742	6	15	1					49	58.2	4.1
162	4.161176	1	32	31	17	7	2		35	38.3	3.7
163	4.048063	1	11	5	2	1		1	34	49.8	2.9
164	4.190670	1	23	3			1		25	42.8	1.4
165	4 663664	1	19						22	32.4	2.5
166	4.098101	2	21	9	3	1			32	43.9	2.3
167	4.064083	2	13						19	42.8	2.9
168	4.036046	2	8						25	48.9	2.9
169	4.083107	2	12	16	3	6			46	38.7	4.6
170	4.073074	2	15	9	3	3			41	44.5	2.7
171	4.188669	3	18	18	4	3			39	41.5	2.2
172	4.121626	4	32	48	25	19	1		46	38.0	4.7
173	4.006182	4	20	2	1				25	36.8	2.5
174	4.182801	4	13	3	2				29	42.8	2.4

Table E.1 (continued)

175	4	017020	4	20	17	5	3		1	38	46.5	2.6
176	4	159634	4	22	11	5	4	1		18	36.8	3.5
177	4	148149	4	24	2	1				17	43.5	3.3
178	4	141149	6	22						22	42.7	2.7
179	10	202213	1	9	3					23	35.3	1.9
180	10	203213	1	10	3					24	35.1	2.9
181	10	164641	1	19	3	1				13	40.3	2.9
182	10	129660	2	23	19	8	6			63	38.8	3.1
183	10	203212	2	18						20	42.9	1.9
184	10	212213	2	15	1	1				22	35.9	1.7
185	10	111112	3	36	5	3	1			22	36.3	1.4
186	10	093111	3	31	16	9	3			21	40.5	2.0
187	10	168193	3	13	8	4	2			32	37.7	2.8
188	10	057076	4	26	35	16	6		1	71	44.0	4.6
189	10	056057	4	26	2	1	1			14	39.8	2.8
190	10	024757	4	21	22	7	8	1		30	34.8	4.0
191	10	066093	4	34	57	22	12		1	63	39.1	1.6
192	10	061066	4	28	23	9	7			36	38.4	2.1
193	10	168210	4	25	21	5	7		1	36	35.1	3.2
194	10	167171	5	27	3					15	35.5	1.7
195	10	051052	6	27	5	4	2			17	40.8	2.0
196	24	066736	1	16	13	2	4		1	60	43.1	2.1
197	24	037044	1	20	16	4	2			79	44.6	3.4
198	24	034037	1	20	3		1			21	43.1	2.8
199	24	042044	1	10	6		2	1		88	48.5	3.9
200	24	082088	1	10	6		1			45	46.5	3.4
201	24	136144	1	18	9	1	3			56	40.6	2.3
202	24	151732	1	12						21	49.7	3.5
203	24	146147	1	13	10	2	3			53	41.9	3.6
204	24	056059	1	13	9	1	1			65	46.6	4.1
205	24	144151	2	39	12	1	2		1	58	40.4	3.1
206	24	066701	2	16	19	7	3	1		92	41.8	1.8
207	24	008009	2	24	4	1	1			33	42.8	3.1
208	24	123124	2	15	1					22	47.7	3.2
209	24	059060	2	13	4	2	2	1		40	42.3	3.8
210	24	137147	2	14	22	3	6			67	41.7	3.1
211	24	173182	2	20	30	6	9			86	44.0	4.4
212	24	131132	3	39	18	6	11		5	19	36.4	3.9
213	24	156161	3	32	8	6	3			16	39.4	4.0
214	24	036042	4	17	12	4	1		1	86	47.1	3.1
215	24	060104	4	13	19	8	4			57	44.9	2.8
216	24	214216	4	17	6	4	2			26	37.3	3.7
217	24	207708	6	22	19		8	2	1	67	45.1	3.0
218	15	077078	1	25	22	8	6			73	41.3	4.0
219	15	051079	2	13	31	4	8	2	1	159	45.5	3.7
220	15	078104	2	27	19	4	4	1	1	56	41.7	3.1
221	15	102104	2	27	4	2	1			19	52.9	5.8
222	15	077723	2	23	29	9	8	1		116	39.6	4.3
223	15	133200	2	33	26	4	9		1	88	44.0	4.1
224	15	083084	3	26	23	6	7	1	1	50	41.9	3.3
225	15	084086	3	35	10	1	1		1	13	40.9	4.0
226	15	078079	4	34	1	1	1			10	39.1	2.7
227	16	087091	1	27	24	6	4			46	35.9	3.1
228	16	066087	1	21	16	3	5			88	40.3	4.8
229	16	011038	1	17	27	7	2			94	55.8	5.2
230	16	068069	1	13	25	6	7	1	1	92	42.3	2.1
231	16	051703	2	13	8	4	1	1		45	44.7	5.7
232	16	034062	2	16	13	6	1			92	39.8	3.5
233	16	061062	2	16	10	3	1			76	38.2	2.0
234	16	083711	2	13	10	5	2	1		38	39.5	3.1
235	16	022051	3	31	36	17	9			43	40.0	4.1
236	16	038069	3	20	15	4	5		1	31	46.2	4.3
237	16	022027	4	13	17	8	4			28	39.1	2.9

TABLE E.2

Statistical summary of link parameters
(237 links)

Parameter		Mean	Minimum	Maximum	Std.Dev.
SFC	Sideway force coefficient	0.415	0.287	0.582	0.051
TOT	Total number of accidents (3 years)	11.954	0.0	62.000	11.979
PED	Number of accidents involving pedestrians	3.498	0.0	29.000	4.785
WET	Number of wet-road accidents	3.270	0.0	20.000	3.758
ICE	Number of accidents on snow/ice	0.270	0.0	4.000	0.599
WETSKID	Number of wet-road skidding accidents	0.257	0.0	5.000	0.608
LENGTH	Link length (tens of metres)	48.797	10.000	350.000	40.540
TOTDENS	Accidents per km (3 years)	26.483	0.0	128.571	24.134
WETDENS	Wet-road accidents per km	7.188	0.0	57.895	9.162
DRYDENS	Dry-road accidents per km	18.775	0.0	90.000	17.383
SKIDDENS	Wet-road skidding accidents per km	0.533	0.0	26.316	2.007
PEDDENS	Pedestrian accidents per km	8.667	0.0	55.000	11.611
ACCRAT	Accidents per million vehicle km	1.075	0.0	4.936	0.812
WETRAT	Wet-road accidents per million veh. km	0.281	0.0	1.514	0.296
DRYRAT	Dry-road accidents per million veh. km	0.772	0.0	4.114	0.620
PEDRAT	Pedestrian accidents per million veh. km	0.336	0.0	2.007	0.397
SKIDRAT	Wet skidding accidents per mill. veh. km	0.021	0.0	0.616	0.061
PCWET	Percentage wet	24.450	0.0	100.000	22.032
PCSKID	Percentage involving skidding	6.719	0.0	100.000	18.484
XSWETPKM	Excess wet-road accidents per km	0.261	-5.953	17.500	1.793

TABLE E.3

Distribution of mean SFC values on links

SFC	FREQUENCY n	FREQUENCY %
0.29	3	1.3
0.30	1	0.4
0.32	3	1.3
0.33	6	2.5
0.34	4	1.7
0.35	10	4.2
0.36	12	5.1
0.37	16	6.8
0.38	18	7.6
0.39	12	5.1
0.40	14	5.9
0.41	16	6.8
0.42	19	8.0
0.43	20	8.4
0.44	18	7.6
0.45	13	5.5
0.46	11	4.6
0.47	12	5.1
0.48	8	3.4
0.49	6	2.5
0.50	8	3.4
0.51	2	0.8
0.52	1	0.4
0.53	1	0.4
0.54	1	0.4
0.56	1	0.4
0.58	1	0.4
TOTAL	237	100.0

Table E.4

Coded site parameters for 338 sites treated with anti-skid surfacing

VARIABLE		COLUMNS
CASENO	Case number	1 - 3
BORO	Borough number	4 - 6
SFCSG	SFC after treatment	7 - 9
SFCSGC	Adjusted SFCSG reading	10 - 12
SFC1	SFC ahead of treatment area	13 - 15
SFC2	SFC beyond treatment area	16 - 18
GRIDREF	National grid co-ordinates	19 - 27
YEAR	Treatment year	28 - 30
LANDUSE	Roadside land use category	32 - 32
DRYACCB	Dry-road accidents before treatment (3 years)	34 - 35
WETACCB	Wet-road accidents before treatment	36 - 37
TOTACCB	Total number of accidents before treatment	38 - 39
WETSKDB	Wet-road skidding accs. before treatment	40 - 40
WETSHNTB	Wet-road shunt accidents before treatment	41 - 41
PEDACCB	Pedestrian accidents before treatment	42 - 43
DRYACCA	Dry-road accidents after treatment (3 years)	44 - 45
WETACCA	Wet-road accidents after treatment	46 - 47
TOTACCA	Total number of accidents after treatment	48 - 49
WETSKDA	Wet-road skidding accs. after treatment	50 - 50
WETSHNTA	Wet-road shunt accidents after treatment	51 - 51
PEDACCA	Pedestrian accidents after treatment	52 - 53
EXPTOT	Expected accident total in after period	55 - 58
TRAFFIC	Total daily vehicle flow in thousands	60 - 61
TRAFFIC2	Traffic flow on minor road at junctions	62 - 63
TYPE	Location type (junction or ped. crossing)	64 - 65

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  1 12 62 62 33 30 24067970 75 1031 23300 6 7 1 800 3 30.9 3712 1
  2 10 59 59 42 38 27097616 74 2023 932021428 3310015 31.2 2813 1
  3 10 62 62 41 34 25907376 74 2010 71710 615 21702 8 14.9 26 5 1
  4 10 66 66 34 32 27007523 80 2018102800 815 31800 6 22.6 2812 1
  5 10 66 66 35 32 27807555 74 2021 93010 721 4250012 33.2 2915 1
  6 24 65 65 32 37 20507540 74 2018 72602 518 11900 9 26.9 3110 1
  7 23 69 69 36 38 17787147 74 2316 42000 2 6 51100 3 19.9 24 8 1
  8 23 68 68 32 34 18207004 79 1010 81801 3 9 11000 3 16.6 2115 1
  9 22 62 62 36 34 27796905 74 2020 525001320 7271016 19.6 3028 1
 10 22 65 65 43 38 28106836 78 4113 72013 4 9 51600 5 18.4 3015 2
 11 22 68 68 32 36 29076776 80 40 7 71411 116 42001 2 13.4 31 8 1
 12 22 65 65 36 36 24667075 74 2026 632012013 11501 8 31.2 3310 1
 13 21 64 64 44 42 28606477 74 2017 92611 510 51500 2 26.9 1815 1
 14 21 67 67 46 46 24796513 74 2128 53301 318 42200 5 27.3 2715 1
 15 21 69 69 24 36 24296358 74 20 8 41200 3 7 1 800 4 13.3 2623 1
 16  1 65 65 36 36 30888076 80 40 6 81412 1 5 81322 1 13.4 56 8 2
 17  1 65 65 31 29 30678066 80 4320 828531113 31601 3 22.6 5810 1
 18  1 57 65 31 33 29367873 74 2320 424001431 4350217 22.9 21 8 2
 19  1 61 61 34 31 26208064 76 14 7 61301 310 11100 3 14.3 51 7 2
 20  1 68 68 36 32 27927975 79 21 7101731 411 41502 8 14.6 82 7 1
 21  1 62 62 41 34 26797966 79 1414 51902 423 42713 2 17.2 4546 1
 22  1 58 58 32 34 27258151 73 2031124320284313560224 40.4 3518 1
 23  1 59 59 29 30 26888190 75 2024 22600 92310330418 22.0 34 8 1
 24  1 60 60 32 28 26258262 74 1017112800 619 52402 5 22.6 2910 1
 25  1 61 61 25 30 27388179 74 3112132522 9 8 41200 2 19.6 6218 1
 26  1 65 65 26 36 28058202 74 3010 61612 9 8 31210 8 17.3 70 8 1
 27  1 66 66 32 38 28727931 75 30 3 3 611 1 2 1 300 2 10.1 2622 1
 28  1 60 60 36 35 29458132 80 2011142502131 4 62001 8 21.0 35 7 1
 29 11 58 58 30 30 21888011 73 2111132412 326 9350212 20.3 2319 1
 30 12 64 64 29 26 27897919 76 1018 42200 3 4 1 500 1 20.3 2714 1
 31 12 66 66 34 27 25577818 77 2024 832111610 41401 7 30.9 2320 1
 32 12 63 63 28 30 26177769 78 2027 83502 718 11900 4 31.6 2520 1
 33  5 68 68 36 36 35648214 73 2314 41801 719 4230011 16.3 4610 2
 34  5 64 64 39 32 34518173 73 2034 6400223291443 0424 35.6 4015 1
 35  5 61 61 34 32 38158103 73 2016102633 321 3240011 24.5 5015 2
 36  2 69 69 31 21 30578138 73 2313 619111327 6330020 18.4 4615 1
 37  2 62 62 36 34 29978231 73 3023 730001313 21500 4 26.8 2317 1
 38  2 53 65 30 26 29768259 73 3034114522203612481118 39.5 5923 1
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Table E.4 (continued)

39	2	63	63	23	31	25258386	73	20281240142124	2270014	35.6	3112	1
40	2	57	65	32	32	25078409	75	2023 629011321	1220011	29.9	3116	1
41	2	65	65	39	41	29028366	73	2029 534001317	42100 9	26.4	3120	1
42	2	62	62	40	36	29738488	73	1016 72321 221	42501 6	22.3	4410	1
43	2	59	59	36	40	29268429	73	3113 41700 516	82400 5	16.3	4215	1
44	2	63	63	27	40	29108403	74	1039 94821 933	3360015	36.7	3821	1
45	2	62	62	36	35	29238248	75	30201232001212	61801 9	32.0	3410	1
46	2	60	60	35	30	30008153	75	30 4 3 701 4 3	3 610 5	9.4	2712	1
47	2	63	63	20	24	28088366	76	10 7 1 800 2 3	3 601 3	11.8	21 8	2
48	2	61	61	28	32	29178308	76	1013 82115 3 9	41310 5	21.3	3410	1
49	2	56	65	40	40	29958271	77	30121325131115	31800 7	21.6	45 8	2
50	2	63	63	24	24	31128161	79	3011 92010 7 9	81713 4	18.2	3418	2
51	9	61	61	48	48	31947711	74	1231 435001126	73321 7	27.9	36 8	1
52	9	65	65	24	40	30477674	73	102811391211 8	51300 5	27.7	2416	1
53	9	58	58	29	31	32437299	77	1013112431 1 7	61301 0	20.6	2915	1
54	9	64	64	44	44	30707442	73	2012 82035 4 7	1 800 6	18.0	35 8	1
55	9	63	63	32	36	30797463	74	1227 835121424	52900 8	27.9	34 8	1
56	25	64	64	37	38	10877378	73	1018 32100 824	52900 6	19.9	2818	1
57	25	67	67	43	38	12077255	73	1016 72302 718	32102 5	22.3	3714	1
58	25	69	69	33	36	20917711	76	10 3 1 400 1 8	21000 2	10.0	33 7	1
59	25	66	66	38	40	10547435	76	2025 83302 514	41800 0	31.6	3117	1
60	25	65	65	32	32	12767528	79	20301242031722	22400 7	30.4	2615	1
61	26	66	66	38	31	9497922	75	3222 62800 619	72601 8	22.3	3215	1
62	26	63	63	43	33	7428268	75	2313 51802 016	42001 5	18.2	3024	2
63	27	68	68	30	31	17768073	73	3023 933231820	4240210	25.4	3512	1
64	27	63	63	34	39	18638055	73	40321850011145105502 9		48.7	4426	1
65	28	66	66	39	29	20528855	73	3224 83210 714	41800 4	25.3	2314	1
66	28	65	65	46	38	18498620	73	2011 71800 211	31400 2	16.3	2116	1
67	28	68	68	39	28	23228466	74	2010 818001110	21200 5	17.3	2018	2
68	28	65	65	37	32	20268869	80	1215 72201 315	62110 1	20.5	2312	1
69	29	66	66	48	42	13388824	75	10 8 71500 213102312 3		16.6	3014	1
70	29	75	75	47	41	13398627	77	1220 72700 719	52400 6	22.6	2916	1
71	29	65	65	39	42	15428972	79	2012 92100 815	31800 8	18.9	2315	1
72	29	65	65	36	40	14849263	79	40 3101410 0 8	1 900 0	12.3	2012	1
73	16	66	66	45	50	47798581	73	2030 737001130	3330012	32.7	2016	1
74	16	66	66	40	41	49058486	73	2012 92110 511	31400 8	19.9	1811	1
75	16	67	67	40	38	45278507	76	2017 52200 720	72712 9	20.3	2714	1
76	3	59	59	25	28	30638583	73	20341044231434	6400010	42.3	4130	1
77	3	69	69	28	36	30728367	73	2020 727001014	41800 4	20.3	1514	1
78	3	59	59	29	29	31428207	73	3022 42600 723	73000 7	24.5	2822	1
79	3	58	58	24	30	31128310	73	3011 920011014	31700 8	18.0	3013	1
80	3	62	62	35	40	32978481	73	2126 228001327	12901 8	24.6	2115	1
81	3	55	65	28	31	30268702	75	2015 82300 7 6	61210 2	21.4	1610	1
82	4	70	70	28	36	32058748	73	2034 943401951	9611025	40.4	3736	1
83	4	59	59	42	38	33538478	73	2040105001143812510219		48.7	2826	1
84	4	65	65	48	38	33628655	73	2015 419001112	21500 6	18.4	1612	2
85	4	66	66	38	42	32428768	73	1013 61911 814	11511 3	18.4	36 8	2
86	6	60	60	32	34	40317835	73	2014 418011118	52300 9	16.3	3118	1
87	6	66	66	36	26	40497697	80	1012 51921 112	01200 1	17.5	4315	2
88	6	58	58	29	31	44267571	80	4010 31310 2 8	21000 1	12.9	30 8	2
89	6	61	61	23	38	44557535	80	40 7 81503 110	21202 0	13.5	35 7	1
90	6	66	66	35	32	42617311	78	1020 72710 714	51902 4	21.8	37 9	1
91	20	64	64	35	28	31156524	74	2112 21400 7 9	21110 3	15.3	3715	1
92	20	63	63	32	32	32156604	74	2026 329011330	4340121	25.3	2613	1
93	20	62	62	27	33	34046847	75	2019 827001212	92110 9	24.3	1717	1
94	19	60	60	43	43	38276638	75	2111102101 513	01300 4	20.9	1816	1
95	19	64	64	44	29	41056512	74	40 9 51502 1 7	0 700 0	16.4	20 5	1
96	19	74	74	35	46	46866754	80	3016 72300 9 7	31011 6	17.8	3610	1
97	19	67	67	33	24	47056848	77	3113 41700 414	62110 2	17.7	3510	1
98	7	62	62	35	31	38127507	73	2019 42300 910	41400 5	22.3	4115	1
99	7	66	66	34	34	38337561	75	2033 740011228	9370115	35.6	2812	2
100	7	63	63	25	25	38397560	79	20 8 91710 612	31500 4	14.6	2621	1
101	7	65	65	34	35	38257579	73	2038 746121815	6210012	33.8	4030	2
102	7	70	70	45	36	38947368	75	1010 51510 316	11701 3	16.6	3015	1
103	8	67	67	42	28	33237317	80	41 8111911 1 9	51402 0	17.5	2614	1
104	8	66	66	32	33	34407548	80	2412 92200 523	42700 9	20.5	2521	1
105	8	66	66	34	33	34457677	74	2117 62301 923	1240011	21.7	2726	1
106	8	67	67	30	30	32467975	74	3010 21200 815	41901 6	13.3	2215	1
107	8	67	67	29	30	31658040	74	3011 71900 417	2191112	18.7	4225	1
108	8	62	62	33	32	34057951	75	1015 419001314	21600 8	19.5	3210	1
109	8	62	62	30	23	33397938	74	1011 41511 711	31401 3	16.4	2410	1
110	8	66	66	34	35	32297960	74	3014 62001 3 8	31101 2	19.9	2414	1
111	8	65	65	36	36	32197951	74	30 8 21000 2 7	31000 1	12.0	2711	1
112	13	64	64	36	35	36378720	73	21 9 41422 3 5	1 601 3	12.6	4015	1

Table E.4 (continued)

113	13	60	60	30	32	37808815	73	20321245122427	9360022	39.5	3128	1
114	14	67	67	33	38	44048657	77	2017 522021128	5340220	18.8	3518	1
115	14	66	66	39	39	40338759	77	4111 31410 1 7	21000 1	15.0	2921	1
116	14	65	65	46	38	40278876	78	2410 61630 3 7	2 900 2	14.8	2017	1
117	18	70	70	50	35	51467477	76	21 7 71400 513	41702 7	14.7	2218	1
118	18	66	66	40	50	49677513	73	2112 92110 2 9	51400 6	19.9	1714	1
119	30	63	63	38	38	24638626	74	1036215732 920	72701 5	36.2	5314	1
120	30	70	70	47	44	26479142	77	1011 51621 5 7	41100 1	15.8	2615	1
121	30	68	68	35	37	26419197	73	2020133311 825	5310111	25.4	2622	1
122	30	54	65	33	32	25068643	75	2323 83100 922	52700 5	28.3	2414	1
123	31	62	62	39	42	29388929	79	21 9 61600 219	42311 7	12.9	2618	1
124	31	62	62	32	32	31778877	73	2011 11200 818	32101 6	13.3	2915	2
125	31	58	58	32	32	31578948	76	14 7 51200 6 6	2 800 3	14.4	3210	2
126	31	64	64	32	29	29989144	78	2311112203 617	32000 6	20.0	2514	1
127	32	60	60	31	35	32349690	80	40 5 51111 1 7	41101 2	11.9	2810	1
128	1	69	69	38	28	30358008	75	40 4 81223 415	31812 4	13.2	33	
129	1	63	63	31	33	29227882	74	1312 31510 7 9	11000 6	14.1	20	
130	1	61	61	44	38	27188086	74	14 6 1 701 1 7	1 800 1	8.4	49	
131	1	65	65	42	36	25568173	76	2115 520001217	7240214	18.0	25	
132	1	65	65	36	30	25698349	78	1020 92912 920	12200 7	20.5	38	
133	1	64	64	34	34	27188159	76	2018 725021012	7190110	17.2	32	
134	1	58	58	30	34	26728204	74	2013 3160011 9	21200 5	15.4	37	
135	1	64	64	35	33	26588219	74	2118 927121015	52001 6	15.0	37	
136	11	58	58	40	29	25707634	78	21 4 5 911 6 3	2 500 4	6.9	21	
137	11	57	65	38	34	25357652	73	14 3 1 400 2 6	3 900 5	5.7	26	
138	11	63	63	34	26	23487963	80	2114 82222 7 4	3 701 6	18.5	38	
139	12	68	68	45	34	24648021	75	2116 117001016	11700 7	18.7	39	
140	12	68	68	32	36	25857789	75	10 2 1 300 1 1	1 200 1	6.6	20	
141	12	65	65	32	29	25867808	75	10 9 31201 1 3	0 400 1	13.2	22	
142	12	63	63	26	27	27887931	76	21 5 2 700 2 5	0 500 1	8.9	27	
143	5	67	67	38	32	35018222	75	30 5 91402 5 6	41011 3	13.5	28	
144	5	67	67	40	36	34578322	75	2013 21500 310	31311 2	13.2	26	
145	5	62	62	34	35	34498319	75	20 4 1 510 4 1	2 300 1	7.0	26	
146	5	62	62	38	35	34418317	75	20 5 4 900 6 9	31200 6	7.7	26	
147	5	67	67	37	32	34268313	75	20 7 31012 314	51903 5	12.6	26	
148	2	66	66	39	23	31108209	79	10 2 6 822 1 1	4 522 1	7.4	17	
149	9	68	68	41	35	30417843	75	30 4 0 400 3 6	1 700 3	7.1	35	
150	9	68	68	34	33	30938000	75	32 8 1 900 5 8	4120010	7.7	30	
151	9	64	64	36	42	31167996	76	32141327421312	5170110	29.0	27	
152	9	70	70	38	39	30877706	73	1314 519011114	41812 5	17.8	30	
153	9	66	66	42	23	30317746	74	10 9 21121 5 5	0 500 3	11.4	26	
154	9	66	66	46	46	31787436	77	10 3 5 822 2 1	2 301 0	8.0	15	
155	9	62	62	26	31	31867241	77	20 7 1 800 4 3	3 602 2	8.0	26	
156	9	66	66	36	29	30367504	73	20 810181112 3	4 700 5	14.5	26	
157	9	66	66	42	38	30517014	75	3121 42500 515	11600 3	21.5	43	
158	9	60	60	25	29	30097182	78	20311041331817	8251213	22.0	38	
159	9	64	64	38	40	31207668	77	1012 21400 9 9	31221 5	12.8	35	
160	9	66	66	34	39	31007733	74	23131427201311	41620 7	15.0	30	
161	25	64	64	34	36	10807360	73	10 4 4 820 5 4	0 400 0	9.1	22	
162	27	63	63	27	26	19548022	76	10 3 71011 4 6	3 900 6	11.6	24	
163	27	66	66	34	33	20898003	78	30 2 3 500 2 4	0 400 0	6.2	29	
164	27	69	69	24	36	19447965	75	30 8 41221 611	11200 7	13.2	20	
165	27	73	73	35	31	13758491	76	10 8 61400 6 5	41100 3	12.1	39	
166	27	58	58	32	29	20178088	76	21 5 61120 3 6	3 900 6	9.5	17	
167	27	70	70	39	40	14488502	80	13 6 51112 2 5	0 500 0	9.5	20	
168	27	70	70	36	26	15937948	80	10 6 2 810 2 6	0 600 2	9.1	18	
169	27	65	65	26	29	15797963	80	20 4 61111 3 6	2 801 2	9.3	18	
170	28	67	67	43	42	18148441	76	2010 71700 9 9	51401 8	18.8	22	
171	28	63	63	44	44	18198418	76	20 5 4 900 5 9	11000 8	11.0	22	
172	28	63	63	38	42	23688537	77	101211230210 6	1 700 2	17.3	16	
173	28	67	67	28	36	24458408	77	10 9 41400 1 3	3 600 2	12.8	13	
174	29	68	68	47	34	14188633	77	2010 31301 3 6	3 900 4	14.5	24	
175	15	64	64	41	41	52228742	75	10 7 41120 4 6	2 800 0	9.7	25	
176	15	69	69	35	44	50108841	73	2311 71812 5 9	11000 7	14.5	29	
177	15	68	68	40	37	52708738	77	20 4 1 501 3 0	1 100 1	6.5	25	
178	15	65	65	38	40	53098728	77	10 3 1 400 0 1	2 300 1	5.5	25	
179	16	64	64	36	32	50308501	76	30 5 51114 2 6	1 700 2	9.5	29	
180	16	66	66	36	32	50298490	78	20 9 11001 413	61922 8	8.3	29	
181	16	70	70	42	37	50248518	78	3023103311 911	62010 8	14.0	29	
182	16	68	68	43	43	48448859	77	10 2 1 301 0 3	1 400 3	5.4	28	
183	17	67	67	38	36	42828257	74	1012 11300 4 9	41310 4	13.7	19	
184	17	67	67	35	37	42678338	77	20 7 51200 6 3	1 400 1	11.8	19	
185	17	51	65	28	27	42408401	75	20 9 0 900 6 7	2 900 3	7.7	20	
186	17	62	62	35	38	42338427	75	2014 51900 911	3140011	16.8	20	
187	17	61	61	38	30	42238468	75	20 6 61210 410	01000 3	13.2	20	
188	17	61	61	34	32	42218486	75	20 8 31100 7 3	0 300 0	9.7	20	

Table E.4 (continued)

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189 17 64 64 40 32 42108534 75 10 6 2 800 4 3 1 400 1  9.2 20
190 17 63 63 38 33 41658327 77 2010 41401 3 6 2 800 2 12.9 26
191 17 64 64 30 30 40598012 77 30 5 3 800 1 4 1 700 2  8.1 18
192 17 60 60 38 29 39698356 77 21 9 41301 312 31500 8 14.5 21
193 17 68 68 38 40 40438314 80 21 1 3 401 0 1 2 301 0  5.4 21
194 17 67 67 21 41 40638304 80 31 1 3 510 1 2 2 401 2  6.3 22
195 17 68 68 40 35 40628450 80 12 2 2 410 210 01000 6  5.4 18
196  3 58 58 32 39 30958543 73 2013 61902 821 22300 9 17.8 46
197  3 66 66 29 23 31948392 73 2018 624101114 4180110 25.0 28
198  3 61 61 36 32 32048292 77 1316 21800 612 71900 4 17.2 27
199  3 56 65 28 32 32308282 75 30 6 1 700 4 9 21111 5  7.3 28
200  3 68 68 34 32 32758239 80 30 5 1 600 4 6 0 600 2  6.3 30
201  3 61 61 35 26 31688381 73 2010 61600 521 12200 7 11.3 21
202  3 66 66 24 35 31698400 75 2011 21300 711 21300 8 14.1 25
203  3 59 59 34 28 31648419 76 2015 621011015 21801 2 18.4 25
204  3 65 65 33 28 29218628 75 21 7 81501 5 6 41021 4 13.2 16
205  3 55 65 26 31 30758303 75 23 4 0 400 0 5 1 600 3  7.1 17
206  3 60 60 38 30 31238309 75 1312 11300 6 8 41200 4 14.1 30
207  3 58 58 32 30 31248700 76 20 7 51211 5 7 2 911 6  9.9 17
208  3 61 61 41 39 32018423 77 10 2 5 700 3 8 21001 4  7.0 25
209  3 62 62 29 28 31938588 80 12 4 1 501 3 0 3 310 2  6.3 16
210  3 66 66 31 30 31158653 80 20 8 21000 5 8 21001 5  9.3 27
211  3 65 65 29 29 31918637 80 20 9 51520 8 6 0 700 3 13.9 16
212  4 64 64 29 29 32538367 80 12 9 21100 5 7 0 700 0  9.3 34
213  3 66 66 26 25 32388394 80 10 2 1 300 0 4 0 400 1  5.0 34
214  3 58 58 29 27 32478382 80 2017 52201 711 21300 3 14.5 34
215  4 64 64 41 26 31878719 77 10 3 2 501 014 4180110  6.5 36
216  4 65 65 27 27 31888791 77 1015 31801 5 4 61101 5 17.2 37
217  4 69 69 28 30 32348660 74 10 6 2 811 4 2 1 300 0  7.0 25
218  3 65 65 27 27 32378632 75 4112 31500 3 5 2 800 1 13.2 28
219  4 73 73 44 32 32588567 74 20 4 2 611 2 2 2 400 1  7.8 18
220  4 66 66 32 29 32658569 74 20 5 2 711 3 3 2 500 1  8.4 18
221  4 60 60 29 29 34818589 74 1213 61923 7 7 2 910 3 17.1 12
222  4 67 67 38 35 34558699 80 1010 41411 411 31401 3 13.6 32
223  4 66 66 32 32 34648675 80 2014 11500 311 11200 6 13.9 32
224  4 62 62 34 32 35108552 78 2014 41820 7 6 3 900 6 12.2 30
225  4 70 70 37 38 33478334 78 1316 1170010 5 4 900 4 11.6 29
226  4 57 65 28 31 32758329 74 10 4 1 500 3 6 2 800 5  6.8 34
227  4 62 62 30 32 32618357 74 30 8 81610 9 5 4 901 2 15.4 34
228  6 68 68 27 26 37757674 75 30 9 21101 7 5 2 711 2  9.7 32
229  6 67 67 38 34 41787563 73 101111223414 9 41300 6 16.2 29
230  6 68 68 41 39 45697846 77 2011 41501 5 6 2 800 5 13.0 28
231  6 64 64 29 33 45137868 77 20 4 0 400 3 7 31001 7  5.5 33
232  6 62 62 32 32 44237892 74 30 8 21001 1 6 3 900 2 11.0 33
233  6 62 62 27 38 38257741 77 30 7 71435 7 5 41001 6 12.8 25
234  6 73 73 40 36 42457448 76 21 2 5 700 6 2 2 401 1  8.9 21
235 20 66 66 30 34 30996857 77 2013 82113 9 8 51301 5 18.0 34
236 20 67 67 32 34 31146407 77 31 1 6 711 1 4 2 601 2  7.0 33
237 20 68 68 36 37 31796209 74 20 3 5 800 6 3 0 300 2  7.0 25
238 20 63 63 38 42 32536380 75 13 8 51312 2 5 2 700 3 14.1 37
239 20 66 66 40 36 32916724 78 20 7 31001 3 4 1 500 4  8.3 14
240 20 70 70 43 42 33366800 79 10 3 1 400 0 5 1 601 2  5.5 14
241 20 68 68 39 40 34496899 79 21 4 1 500 3 1 2 300 1  5.9 16
242 20 69 69 40 39 32417035 77 14 8 1 900 110 11100 2  7.5 22
243 20 71 71 47 48 33346503 80 10 1 0 100 0 1 2 311 2  4.6 16
244 20 65 65 39 35 34506658 75 20 7 1 800 3 5 51000 5  9.2 19
245 20 70 70 30 36 34256636 75 20 4 2 600 3 3 0 300 0  8.5 19
246 20 71 71 35 30 34146629 77 20 4 1 500 1 6 1 700 3  6.5 19
247 19 68 68 41 40 37386754 78 30 3 4 710 1 7 2 900 2  6.5 14
248 19 65 65 37 36 46146604 77 2010 11100 3 8 1 900 2 10.0 23
249 19 68 68 41 40 42066574 77 10 3 1 400 1 1 0 100 0  5.5 10
250 19 66 66 39 37 41376793 74 1210 51510 713 31610 9 14.2 36
251 19 66 66 40 33 40276898 77 20 7 31001 117 7241112  9.2 39
252 19 66 66 36 32 40036945 77 20 5 2 700 5 7 0 700 2  7.0 20
253 19 69 69 32 32 36636950 77 30 3 0 300 2 3 2 500 2  5.4 24
254 19 64 64 39 38 35936975 77 10 4 0 400 4 6 2 801 3  5.5 24
255 19 65 65 36 33 36076842 77 23 7 1 811 4 2 1 300 1  8.1 19
256  7 65 65 34 34 38247593 77 23 1 2 310 2 2 0 200 1  5.4 18
257  7 61 61 37 36 35537303 77 20 9 11000 413 21500 7  9.2 25
258  7 64 64 39 32 36747329 77 20 8 0 900 6 5 2 701 2  7.5 27
259  7 65 65 26 27 39397519 76 20 8 1 900 6 3 2 501 2 11.0 19
260  7 58 58 38 28 38827522 75 20 5 3 801 317 42101 4  9.2 19
261  7 68 68 33 28 38017582 76 3116 42000 911 51603 5 18.2 41
262  7 62 62 27 29 37737592 76 2012 01200 613 51801 6  9.9 36
263  8 70 70 33 40 33677449 80 10 6 2 811 4 5 0 500 2  7.5 18
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Table E.4 (continued)

264	8	64	64	26	28	33477503	76	12 5	0 500	0 6	1 710	3	7.1	16
265	8	58	58	42	35	34257629	77	2010	21200	5 6	3 900	7	11.8	18
266	8	58	58	39	42	34337613	77	20 8	1 910	4 5	1 600	2	7.5	18
267	8	60	60	28	33	33617679	74	3014	51903	823	73011	12	17.1	35
268	8	62	62	32	27	34637677	76	10 8	21000	2 3	0 300	2	11.6	30
269	8	64	64	24	29	33387853	76	20 9	31212	8 4	0 400	0	9.9	51
270	8	66	66	35	26	32797922	77	13 5	51001	4 1	4 500	3	9.2	18
271	8	69	69	34	35	32557954	77	10 2	3 500	0 2	4 600	2	6.5	10
272	8	65	65	38	37	35317924	77	1011	61711	3 1	1 200	1	14.6	31
273	8	59	59	36	34	32127949	78	30 1	3 400	3 0	0 000	0	5.0	28
274	8	63	63	36	34	31997924	78	3010	31300	6 8	61402	6	12.0	27
275	8	62	62	42	41	32407779	78	2020	22201	6 9	51400	9	16.7	39
276	8	62	62	38	40	32457790	78	2022	42601	1010	61600	8	14.0	34
277	8	62	62	40	40	32437799	78	20 4	4 910	3 7	2 911	2	6.9	29
278	8	64	64	40	40	32397808	78	20 9	31200	414	11500	8	10.0	29
279	8	69	69	38	39	31477959	80	30 7	2 900	4 2	1 300	1	6.9	19
280	8	64	64	30	24	32298027	77	30 3	2 501	1 7	1 800	0	6.5	20
281	13	63	63	36	34	37298779	75	21 5	61112	5 0	0 000	0	9.7	33
282	13	64	64	35	34	36678735	77	23 2	4 601	1 0	0 000	0	7.6	40
283	13	62	62	32	34	37908828	77	20 4	1 501	1 0	0 000	0	6.5	31
284	13	66	66	40	29	37998799	73	2014	62002	814	51901	9	16.8	20
285	13	66	66	24	26	38158758	75	2011	21301	4 0	0 000	0	14.1	26
286	13	65	65	28	38	38088729	75	12 4	81241	4 0	0 000	0	13.2	26
287	13	68	68	47	25	39318738	73	23 6	41010	510	31310	6	10.6	15
288	13	59	59	38	35	36118947	75	20 4	3 701	4 7	2 900	4	7.3	27
289	13	68	68	32	31	36938975	75	23 7	41221	6 5	1 600	2	13.2	32
290	13	63	63	35	30	38068986	80	21 8	122030	6 2	0 200	2	17.5	32
291	13	59	59	23	28	36098905	80	10 6	1 710	2 0	1 200	1	7.4	23
292	14	66	66	32	31	44098505	76	21 6	51101	5 4	5 901	0	9.5	29
293	14	72	72	39	32	43978547	77	21 5	1 700	2 5	0 500	2	7.0	29
294	14	70	70	36	32	43878573	77	20 9	31200	4 9	31200	4	11.8	29
295	14	69	69	33	34	43758599	80	20 8	41210	410	21211	4	9.2	29
296	14	66	66	34	33	43638623	80	20 4	3 900	3 4	1 500	2	9.1	29
297	14	70	70	36	36	43778885	76	23 7	2 900	5 4	0 400	0	11.0	15
298	14	70	70	42	42	47618785	76	2020	62610	916	31900	2	17.7	25
299	18	68	68	52	50	51587649	75	13 5	61103	4 5	0 500	3	9.7	20
300	18	70	70	40	44	49277831	78	10 8	21000	011	31400	6	8.3	20
301	31	64	64	36	29	32498922	78	2012	41600	710	41402	4	13.8	19
302	31	67	67	29	31	32808809	74	21 5	1 601	1 8	31102	5	7.8	28
303	31	64	64	30	30	33468874	73	32 7	51221	5 7	2 901	2	12.0	29
304	31	65	65	38	28	30889139	76	1313	51801	811	41611	6	15.5	28
305	31	64	64	32	36	30129131	80	31 8	61402	8 6	2 800	3	13.6	28
306	32	68	68	46	46	29339245	75	30 5	1 600	3 5	1 600	3	8.5	13
307	32	66	66	35	35	33779645	74	10 1	4 511	2 4	3 701	1	6.8	28
308	32	62	62	31	31	35539853	75	20 8	1 900	5 5	2 711	2	7.7	29
309	32	58	58	35	30	35479829	75	30 5	3 801	5 8	51300	4	9.2	29
310	32	68	68	40	40	34859460	76	23 6	1 700	6 2	0 200	0	8.9	23
311	32	68	68	44	42	34159274	77	2011	21300	710	31301	1	14.5	29
312	11	61	61	36	30	25697642	78	2014	62001	1212	41601	8	14.2	21
313	11	55	65	36	40	25747603	78	10 5	0 500	3 1	0 100	1	6.2	21
314	11	68	68	33	34	22227929	75	10 3	3 601	3 9	0 900	2	8.5	31
315	12	62	62	24	28	27837953	76	20 9	31200	3 4	0 400	2	9.9	28
316	12	64	64	39	39	26697761	77	20 9	21100	7 0	0 000	0	10.0	29
317	10	66	66	40	41	26237209	79	2014	11500	4 8	21020	2	14.4	25
318	10	69	69	26	26	28917056	77	20 4	71112	2 5	51000	4	10.0	20
319	10	68	68	28	28	29057073	76	10 3	4 710	4 2	0 200	1	8.9	24
320	10	69	69	47	39	26847614	78	31 3	0 300	2 8	1 900	5	4.6	27
321	10	67	67	40	35	25297347	79	3112	41601	5 8	31110	2	11.5	23
322	10	73	73	28	31	27747571	76	10 1	1 210	1 2	3 500	1	4.8	15
323	10	66	66	30	30	28377469	73	40 0	0 000	0 2	1 300	2	4.5	25
324	10	64	64	32	33	28707448	80	40 5	3 811	1 6	2 800	1	7.5	25
325	10	66	66	26	30	27747194	76	2011	61802	814	31700	6	15.5	30
326	10	66	66	35	37	27647183	76	20 6	51101	6 4	1 600	2	9.5	30
327	10	61	61	35	31	27607168	76	20 9	11000	416	52111	7	11.6	30
328	10	68	68	43	39	27347133	76	20 7	71403	6 6	1 700	2	12.1	29
329	24	68	68	28	31	20117531	76	2012	31501	8 7	2 900	5	13.9	31
330	24	66	66	44	32	21797544	74	1012	82024	613	11400	2	16.4	31
331	24	70	70	39	37	19027571	78	1016	122852	612	82014	3	23.0	27
332	24	69	69	39	43	18927708	77	10 4	91340	2 6	2 801	1	14.5	23
332	24	72	72	42	42	18827682	77	10 3	6 911	5 3	1 400	2	7.5	22
334	24	68	68	46	36	18637599	80	10 4	1 500	1 1	0 100	1	6.3	22
335	23	74	74	47	42	18016694	74	10 9	11000	2 4	1 510	2	11.0	21
336	23	61	61	41	41	21576675	80	10 6	51110	2 3	3 600	1	9.3	23
337	22	69	69	36	32	26017007	78	20 7	61322	7 5	3 801	2	12.0	35
338	1	70	70	31	34	30538054	80	40 4	61051	3 3	1 400	4	9.3	59

Parameter		Mean	Minimum	Maximum	Std.Dev.
SFCSG	Sideway force coefficient after treatment	0.646	0.510	0.750	0.039
SFCSGC	Adjusted SFCSG reading	0.649	0.580	0.750	0.034
SFC1	SFC ahead of treatment area	0.351	0.200	0.520	0.060
SFC2	SFC beyond treatment area	0.341	0.210	0.500	0.053
SFCB	Estimated SFC before treatment	0.346	0.220	0.510	0.050
TRAFFIC	Total daily vehicle flow in thousands	28.136	10.000	82.000	9.363
DRYACCB	Dry-road accidents before treatment	11.408	0.0	40.000	7.969
DRYACCA	Dry-road accidents after treatment	10.382	0.0	51.000	8.050
WETACCB	Wet-road accidents before treatment	4.962	0.0	21.000	3.430
WETACCA	Wet-road accidents after treatment	2.982	0.0	14.000	2.429
TOTACCB	Total accidents before treatment	16.444	0.0	57.000	10.106
TOTACCA	Total accidents after treatment	13.459	0.0	61.000	9.744
WETSKDB	Wet skid accidents before treatment	0.580	0.0	5.000	0.950
WETSKDA	Wet skid accidents after treatment	0.180	0.0	2.000	0.443
WETSHNTB	Wet shunt accidents before treatment	0.775	0.0	5.000	1.020
WETSHNTA	Wet shunt accidents after treatment	0.473	0.0	4.000	0.771
PEDACCB	Pedestrian accidents before treatment	5.825	0.0	28.000	4.475
PEDACCA	Pedestrian accidents after treatment	4.864	0.0	25.000	4.461
EXPTOT	Expected accident total in after period	15.168	4.500	48.700	8.104
EXPWET	Expected wet accidents in after period	4.579	0.0	17.532	2.895
EXPDRY	Expected dry accidents in after period	10.506	0.0	38.960	6.569
EXPSKID	Expected wet skids in after period	0.542	0.0	4.650	0.887
EXPSHUNT	Expected wet shunts in after period	0.717	0.0	5.071	0.925
EXPPED	Expected pedestrian accidents in after period	5.376	0.0	26.307	3.859
ACCRATB	Accidents per mill. veh. km before treatment	5.493	0.0	16.895	3.202
ACCRATA	Accidents per mill. veh. km after treatment	4.438	0.0	16.634	2.925
WETRATB	Wet acc. per mill. veh. km before treatment	1.683	0.0	6.279	1.183
WETRATA	Wet acc. per mill. veh. km after treatment	0.998	0.0	4.835	0.789
PCWETB	Percentage wet before treatment	31.217	0.0	85.714	16.957
PCWETA	Percentage wet after treatment	23.369	0.0	100.000	16.799
PCSKIDB	Percentage skid before treatment	10.934	0.0	100.000	19.294
PCSKIDA	Percentage skid after treatment	5.623	0.0	100.000	16.012
PCSHNTB	Percentage shunt before treatment	15.389	0.0	100.000	21.591
PCSHNTA	Percentage shunt after treatment	13.430	0.0	100.000	22.728
XSWETB	Excess wet accidents before treatment	1.134	-8.333	10.333	3.138
XSWETA	Excess wet accidents after treatment	-0.510	-8.333	6.333	2.296
REDUCTN	Net reduction in total accidents	1.709	-20.600	22.900	5.882
REDWET	Net reduction in wet-road accidents	1.597	-8.666	10.500	2.949
REDPM	Net reduction per 1000 sq. metres treated	2.611	-26.909	28.182	8.195
REDWETPM	Net red. in wet acc. per 1000 metres	2.204	-9.400	19.091	4.295

TABLE E.5A Statistical summary of anti-skid surfacing site parameters (338 sites)

Parameter		Mean	Minimum	Maximum	Std.Dev.
SFCSG	Sideway force coefficient after treatment	0.638	0.530	0.750	0.038
SFCSGC	Adjusted SFCSG reading	0.643	0.580	0.750	0.033
SFC1	SFC ahead of treatment area	0.349	0.200	0.500	0.063
SFC2	SFC beyond treatment area	0.345	0.210	0.500	0.055
SFCB	Estimated SFC before treatment	0.347	0.220	0.480	0.052
TRAFFIC	Total daily vehicle flow in thousands	31.614	15.000	82.000	10.892
DRYACCB	Dry-road accidents before treatment	17.134	3.000	40.000	8.749
DRYACCA	Dry-road accidents after treatment	16.252	2.000	51.000	9.035
WETACCB	Wet-road accidents before treatment	7.094	1.000	21.000	3.349
WETACCA	Wet-road accidents after treatment	4.205	0.0	14.000	2.778
TOTACCB	Total accidents before treatment	24.331	4.000	57.000	10.208
TOTACCA	Total accidents after treatment	20.559	3.000	61.000	10.797
WETSKDB	Wet skid accidents before treatment	0.630	0.0	5.000	0.966
WETSKDA	Wet skid accidents after treatment	0.181	0.0	2.000	0.426
WETSHNTB	Wet shunt accidents before treatment	0.929	0.0	5.000	1.121
WETSHNTA	Wet shunt accidents after treatment	0.622	0.0	4.000	0.899
PEDACCB	Pedestrian accidents before treatment	7.785	0.0	28.000	5.569
PEDACCA	Pedestrian accidents after treatment	7.031	0.0	25.000	5.613
EXPTOT	Expected accident total in after period	22.175	9.400	48.700	8.090
EXPWET	Expected wet accidents in after period	6.482	1.108	17.532	2.735
EXPDRY	Expected dry accidents in after period	15.599	2.636	38.960	7.217
EXPSKID	Expected wet skids in after period	0.570	0.0	4.036	0.853
EXPSHUNT	Expected wet shunts in after period	0.851	0.0	5.071	1.022
EXPPED	Expected pedestrian accidents in after period	7.088	0.0	26.307	4.926
ACCRATB	Accidents per mill. veh. km before treatment	7.590	1.107	16.895	3.468
ACCRATA	Accidents per mill. veh. km after treatment	6.325	1.054	16.634	3.284
WETRATB	Wet acc. per mill. veh. km before treatment	2.224	0.277	5.162	1.180
WETRATA	Wet acc. per mill. veh. km after treatment	1.292	0.0	4.835	0.874
PCWETB	Percentage wet before treatment	30.887	6.061	71.429	12.828
PCWETA	Percentage wet after treatment	21.410	0.0	61.538	11.354
PCSKIDB	Percentage skid before treatment	8.290	0.0	62.500	12.994
PCSKIDA	Percentage skid after treatment	4.411	0.0	100.000	12.908
PCSHNTB	Percentage shunt before treatment	12.485	0.0	62.500	14.818
PCSHNTA	Percentage shunt after treatment	16.046	0.0	100.000	26.284
XSWETB	Excess wet accidents before treatment	1.349	-8.333	10.333	3.752
XSWETA	Excess wet accidents after treatment	-1.247	-8.333	6.333	2.853
REDUCTN	Net reduction in total accidents	1.616	-20.600	22.900	7.446
REDWET	Net reduction in wet-road accidents	2.277	-8.666	9.952	3.301
REDPM	Net reduction per 1000 sq. metres treated	1.616	-20.600	22.900	7.446
REDWETPM	Net wet acc. reduct. per 1000 sq. metres	2.277	-8.660	9.952	3.301

TABLE E.5B Statistical summary of anti-skid surfacing site parameters (127 ATS junctions)

Parameter		Mean	Minimum	Maximum	Std.Dev.
SFCSG	Sideway force coefficient after treatment	0.651	0.510	0.740	0.039
SFCSGC	Adjusted SFCSG reading	0.653	0.580	0.740	0.035
SFC1	SFC ahead of treatment area	0.353	0.210	0.520	0.058
SFC2	SFC beyond treatment area	0.339	0.230	0.500	0.053
SFCB	Estimated SFC before treatment	0.346	0.250	0.510	0.048
TRAFFIC	Total daily vehicle flow in thousands	26.043	10.000	59.000	7.602
DRYACCB	Dry-road accidents before treatment	7.962	0.0	31.000	4.922
DRYACCA	Dry-road accidents after treatment	6.848	0.0	23.000	4.649
WETACCB	Wet-road accidents before treatment	3.678	0.0	14.000	2.783
WETACCA	Wet-road accidents after treatment	2.246	0.0	8.000	1.840
TOTACCB	Total accidents before treatment	11.697	0.0	41.000	6.411
TOTACCA	Total accidents after treatment	9.185	0.0	30.000	5.795
WETSKDB	Wet skid accidents before treatment	0.550	0.0	5.000	0.942
WETSKDA	Wet skid accidents after treatment	0.180	0.0	2.000	0.453
WETSHNTB	Wet shunt accidents before treatment	0.682	0.0	5.000	0.945
WETSHNTA	Wet shunt accidents after treatment	0.384	0.0	4.000	0.669
PEDACCB	Pedestrian accidents before treatment	4.649	0.0	18.000	3.135
PEDACCA	Pedestrian accidents after treatment	3.559	0.0	14.000	2.911
EXPTOT	Expected accident total in after period	10.950	4.500	29.700	4.308
EXPWET	Expected wet accidents in after period	3.434	0.0	13.963	2.336
EXPDRY	Expected dry accidents in after period	7.441	0.0	18.750	3.587
EXPSKID	Expected wet skids in after period	0.526	0.0	4.650	0.908
EXPSHUNT	Expected wet shunts in after period	0.636	0.0	4.571	0.854
EXPPED	Expected pedestrian accidents in after period	4.346	0.0	13.963	2.549
ACCRATB	Accidents per mill. veh. km before treatment	4.231	0.0	14.460	2.231
ACCRATA	Accidents per mill. veh. km after treatment	3.303	0.0	10.094	1.951
WETRATB	Wet acc. per mill. veh. km before treatment	1.357	0.0	6.279	1.063
WETRATA	Wet acc. per mill. veh. km after treatment	0.821	0.0	3.533	0.675
PCWETB	Percentage wet before treatment	31.415	0.0	85.714	19.042
PCWETA	Percentage wet after treatment	24.549	0.0	100.000	19.283
PCSKIDB	Percentage skid before treatment	12.526	0.0	100.000	22.120
PCSKIDA	Percentage skid after treatment	6.352	0.0	100.000	17.608
PCSHNTB	Percentage shunt before treatment	17.137	0.0	100.000	24.662
PCSHNTA	Percentage shunt after treatment	11.855	0.0	100.000	20.195
XSWETB	Excess wet accidents before treatment	1.005	-4.667	9.667	2.705
XSWETA	Excess wet accidents after treatment	-0.066	-6.000	4.333	1.745
REDUCTN	Net reduction in total accidents	1.765	-14.800	15.500	4.717
REDWET	Net reduction in wet-road accidents	1.187	-5.170	10.500	2.641
REDPM	Net reduction per 1000 sq. metres treated	3.210	-26.909	28.182	8.575
REDWETPM	Net wet acc. reduct. per 1000 sq. metres	2.159	-9.400	19.091	4.801

TABLE E.5C Statistical summary of anti-skid surfacing site parameters (211 pedestrian crossings)

APPENDIX F

DATA FROM ASSESSMENT OF NODES IN BOROUGH B

(Chapter 9)

TABLE F.1

Data for 130 nodes in Borough B

		COLUMNS
CASE NUMBER	....	1 - 3
SURFACE TYPE	(S = resin/bauxite, 0 = HRA)	6 - 6
RISK RATING	....	9 - 9
TARGET SFC	....	13 - 16
ACTUAL SFC	....	20 - 23
SFC DEFICIT	....	27 - 30
TRAFFIC	(commercial veh. flow per lane) ..	35 - 38
PSV REQUIRED	(based on LR504).................	41 - 42
WET-ROAD ACCIDENTS	(5 years, 1977-81)................	45 - 46
ACCIDENT TOTAL	(5 years, 1977-81)............ ..	49 - 50

3	0	8	0.65	0.48	0.17	2300	83	6	33
6	0	8	0.65	0.45	0.20	2000	81	8	43
9	0	7	0.60	0.42	0.18	900	69	1	6
10	0	8	0.65	0.39	0.26	2000	81	6	16
12	0	8	0.65	0.38	0.27	800	73	3	11
15	0	8	0.65	0.30	0.35	1300	76	6	26
19	0	4	0.45	0.29	0.16	1200	56	4	11
22	0	7	0.60	0.31	0.29	1400	72	2	18
26	0	7	0.60	0.33	0.27	1400	72	2	12
29	0	4	0.45	0.41	0.04	1400	57	0	0
31	0	7	0.60	0.48	0.12	1700	74	5	25
32	0	7	0.60	0.42	0.18	1700	74	2	19
34	0	8	0.65	0.30	0.35	1500	78	5	13
37	0	5	0.50	0.38	0.12	1000	59	4	10
38	0	8	0.65	0.38	0.27	1600	78	3	28
40	0	7	0.60	0.39	0.21	900	69	1	4
43	0	5	0.50	0.37	0.13	1200	61	1	4
46	0	8	0.65	0.35	0.30	2000	81	7	31
47	0	8	0.65	0.29	0.36	1200	76	6	16
51	0	8	0.65	0.37	0.28	1600	78	2	18
53	0	8	0.65	0.42	0.23	900	74	5	18
54	0	8	0.65	0.41	0.24	2100	82	5	26
56	0	5	0.50	0.26	0.24	1000	59	1	8
57	0	8	0.65	0.27	0.38	2100	82	23	67
59	0	8	0.65	0.32	0.33	900	74	4	8
60	0	7	0.60	0.31	0.29	1300	71	11	35
61	0	4	0.45	0.32	0.13	1200	56	5	16
62	0	7	0.60	0.30	0.30	1200	71	9	25
63	0	7	0.60	0.24	0.36	2300	78	12	23
67	0	8	0.65	0.36	0.29	1900	80	11	48
68	0	7	0.60	0.28	0.32	1300	71	6	16
69	0	8	0.65	0.31	0.34	1800	80	14	65
73	0	4	0.45	0.38	0.07	1200	56	1	3
74	0	7	0.60	0.36	0.24	1400	72	3	16
75	0	6	0.55	0.42	0.13	900	64	4	18
76	0	8	0.65	0.32	0.33	2000	81	11	40
77	0	6	0.55	0.31	0.24	900	64	5	11
82	0	8	0.65	0.28	0.37	1300	76	11	43
83	0	5	0.50	0.37	0.13	800	58	3	7
87	0	8	0.65	0.33	0.32	1300	76	25	73
88	0	7	0.60	0.46	0.14	1400	72	5	36
89	0	7	0.60	0.32	0.28	1500	73	3	16
90	0	7	0.60	0.38	0.22	1400	72	2	3
91	0	7	0.60	0.30	0.30	1500	73	3	13
92	0	6	0.55	0.35	0.20	1200	66	3	8
93	0	7	0.60	0.42	0.18	1000	69	3	16
94	0	8	0.65	0.28	0.37	1800	80	4	15
97	0	8	0.65	0.35	0.30	1700	79	12	25
98	0	8	0.65	0.38	0.27	1700	79	3	11
99	0	6	0.55	0.25	0.30	800	63	4	12
100	0	7	0.60	0.37	0.23	800	68	2	17
101	0	9	0.70	0.44	0.26	1300	81	17	50
102	0	8	0.65	0.42	0.23	1700	79	3	23
103	0	5	0.50	0.26	0.24	1100	60	6	21

Table F.1 (continued)

104	0	6	0.55	0.41	0.14	500	61	4	17
106	0	5	0.50	0.34	0.16	1000	59	13	22
108	0	2	0.35	0.34	0.01	1000	44	0	0
111	0	9	0.70	0.42	0.28	2100	87	25	93
113	0	8	0.65	0.31	0.34	1900	80	5	0
115	0	4	0.45	0.32	0.13	1100	55	0	0
116	0	7	0.60	0.44	0.16	2000	76	1	0
117	0	7	0.60	0.45	0.15	2300	78	0	0
118	0	7	0.60	0.28	0.32	2300	78	1	0
120	0	8	0.65	0.30	0.35	2300	83	7	0
121	0	7	0.60	0.35	0.25	2000	76	8	0
122	0	8	0.65	0.38	0.27	2300	83	9	0
124	0	8	0.65	0.25	0.40	1800	80	2	0
125	0	7	0.60	0.35	0.25	1500	73	7	0
126	0	6	0.55	0.35	0.20	2000	71	3	0
127	0	7	0.60	0.40	0.20	800	68	1	0
129	0	3	0.40	0.43	-0.03	1800	55	2	0
1	S	8	0.65	0.62	0.03	2100	82	6	25
2	S	6	0.55	0.50	0.05	2200	72	7	19
4	S	6	0.55	0.60	-0.05	1300	66	3	22
5	S	8	0.65	0.55	0.10	2000	81	9	31
7	S	7	0.60	0.70	-0.10	1000	69	5	22
8	S	6	0.55	0.68	-0.13	1000	64	3	14
11	S	7	0.60	0.63	-0.03	1900	75	17	54
13	S	8	0.65	0.64	0.01	1900	80	9	39
14	S	8	0.65	0.67	-0.02	800	73	2	10
16	S	8	0.65	0.59	0.06	1900	80	4	26
17	S	8	0.65	0.60	0.05	1900	80	8	33
18	S	9	0.70	0.56	0.14	1800	85	9	57
20	S	7	0.60	0.63	-0.03	1400	72	0	3
21	S	7	0.60	0.59	0.01	1300	71	2	10
23	S	8	0.65	0.68	-0.03	2200	82	7	31
24	S	9	0.70	0.67	0.03	1400	82	0	6
25	S	7	0.60	0.64	-0.04	1500	73	7	18
27	S	7	0.60	0.68	-0.08	1500	73	15	53
28	S	7	0.60	0.66	-0.06	1400	72	1	23
30	S	6	0.55	0.65	-0.10	1300	66	2	9
33	S	8	0.65	0.66	-0.01	1800	80	12	39
35	S	8	0.65	0.66	-0.01	1800	80	3	13
36	S	8	0.65	0.70	-0.05	1700	79	15	55
39	S	7	0.60	0.65	-0.05	900	69	6	24
41	S	4	0.45	0.68	-0.23	800	53	0	7
42	S	7	0.60	0.67	-0.07	1500	73	5	32
44	S	6	0.55	0.64	-0.09	1600	68	2	23
45	S	8	0.65	0.66	-0.01	1700	79	12	39
48	S	7	0.60	0.65	-0.05	1300	71	10	46
49	S	6	0.55	0.62	-0.07	1300	66	2	10
50	S	9	0.70	0.63	0.07	2000	86	12	71
52	S	8	0.65	0.54	0.11	800	73	7	20
55	S	8	0.65	0.59	0.06	2200	82	11	41
58	S	8	0.65	0.57	0.08	900	74	5	22
64	S	8	0.65	0.58	0.07	2300	83	19	84
65	S	7	0.60	0.66	-0.06	1300	71	10	27
66	S	7	0.60	0.67	-0.07	1200	71	2	21
70	S	8	0.65	0.69	-0.04	1500	78	7	27
71	S	8	0.65	0.61	0.04	1500	78	13	34
72	S	8	0.65	0.62	0.03	1600	78	14	60
78	S	9	0.70	0.67	0.03	1500	83	24	101
79	S	9	0.70	0.63	0.07	1600	83	21	68
80	S	7	0.60	0.65	-0.05	1300	71	2	11
81	S	8	0.65	0.60	0.05	2300	83	10	40
84	S	7	0.60	0.65	-0.05	1800	75	15	52
85	S	7	0.60	0.58	0.02	1500	73	2	13
86	S	8	0.65	0.69	-0.04	1500	78	2	23
95	S	8	0.65	0.66	-0.01	1100	75	8	46
96	S	6	0.55	0.69	-0.14	1400	67	9	24
105	S	7	0.60	0.62	-0.02	1400	72	9	51
107	S	8	0.65	0.66	-0.01	1000	74	11	35
109	S	8	0.65	0.66	-0.01	1500	78	3	13
110	S	8	0.65	0.67	-0.02	1200	76	11	54
112	S	7	0.60	0.68	-0.08	2100	77	3	0
114	S	7	0.60	0.68	-0.08	1500	73	8	0
119	S	6	0.55	0.64	-0.09	1600	68	8	0
123	S	7	0.60	0.64	-0.04	1800	75	5	0
128	S	6	0.55	0.63	-0.08	1800	70	9	0
130	S	7	0.60	0.62	-0.02	1900	75	7	0

TABLE F.2

Costs and benefits associated with improving SFC at 70 conventionally-surfaced nodes in Borough B which do not comply with LR510

OPTION A ..... Compliance with LR510 using
HRA with PSV as required (up to PSV 72)
- Resin/bauxite at remaining sites

surface type	HRA	resin/bauxite	all sites
PSV	as required	-	-
No. of sites	31	39	70
Overall cost of treatment (present value)	£2,150	£426,300	£428,450
Accident reduction (20 years)	107.6	404.4	512.0
Accident reduction as % of wet-road accidents	24.7	34.9	32.1
Saving in accident costs (present value)	£503,700	£1,893,000	£2,396,700
Net annual economic return (%)	1166.4	17.2	23.0
Cost of preventing one accident	£20	£1,054	£837

Note: See comments in text regarding validity of this assessment

TABLE F.2 (cont.)

OPTION B

- Compliance where possible with PSV up to 72
- At sites where required PSV > 72, resin bauxite used where economically justified (i.e. 2 or more wet-road accidents in 5 years)
- PSV 72 at remaining sites

surface type	HRA	resin/bauxite	all sites
PSV	variable (up to 72)	-	-
No. of sites	34	36	70
Overall cost of treatment (present value)	£2,700	£393,000	£395,700
Accident reduction (20 years)	109.4	401.7	511.1
Accident reduction as % of wet-road accidents	24.6	34.8	32.0
Saving in accident costs (present value)	£512,700	£1,880,000	£2,392,000
Net annual economic return (%)	943.1	18.9	25.2
Cost of preventing one accident	£25	£978	£774

Note: See comments in text regarding validity of this assessment

TABLE F.2 (cont.)

OPTION C
- No resin/bauxite
- HRA with PSV 72 as required (up to PSV 72)
- HRA with PSV 72 at remaining sites

surface type	HRA
PSV	variable
No. of sites	70
Overall cost of treatment (present value)	£8,900
Accident reduction (20 years)	413.7
Accident reduction as % of wet-road accidents	25.9
Saving in accident costs (present value)	£1,936,500
Net annual economic return (%)	1082.9
Cost of preventing one accident	£22

Note: See comments in text regarding validity of this assessment

TABLE F.2 (cont.)

OPTION D - No resin/bauxite
- HRA with PSV 72 at all sites

surface type	HRA
PSV	72
No. of sites	70
Overall cost of treatment (present value)	£12,100
Accident reduction (20 years)	448.7
Accident reduction as % of wet-road accidents	28.1
Saving in accident costs (present value)	£2,100,000
Net annual economic return (%)	862.8
Cost of preventing one accident	£27

Note: See comments in text regarding validity of this assessment

TABLE F.2 (cont.)

OPTION E - Resin/bauxite at all sites

surface type	resin/bauxite
PSV	-
No. of sites	70
Overall cost of treatment (present value)	£765,100
Accident reduction (20 years)	562.6
Accident reduction as % of wet-road accidents	35.3
Saving in accident costs (present value)	£2,634,000
Net annual economic return (%)	12.2%
Cost of preventing one accident	£1,360

TABLE F.2 (cont.)

OPTION F - No resin/bauxite
- Increase of 0.10 in SFC at all sites

surface type	HRA
PSV	72
No. of sites	70
Overall cost of treatment (present value)	£12,100
Accident reduction (20 years)	185.1
Accident reduction as % of wet-road accidents	11.6
Saving in accident costs (present value)	£866,450
Net annual economic return (%)	353.0
Cost of preventing one accident	£65

TABLE F.2 (cont.)

OPTION G - Resin/bauxite at 20% of sites
- No action at remaining sites

surface type	resin/bauxite
PSV	-
No. of sites	14
Overall cost of treatment (present value)	£153,000
Accident reduction (20 years)	295.0
Accident reduction as % of wet-road accidents	36.3 *
Saving in accident costs (present value)	£1,381,000
Net annual economic return (%)	40.1%
Cost of preventing one accident	£519

* accident reduction = 18.5% of accidents at all 70 sites (including 56 untreated sites)

TABLE F.2 (cont.)

OPTION H - Resin/bauxite at 20% of sites
- Increase of 0.10 in SFC at remaining sites

surface type	HRA	resin/bauxite	all sites
PSV	72	-	-
No. of sites	56	14	70
Overall cost of treatment (present value)	£9,700	£153,000	£162,700
Accident reduction (20 years)	90.9	295.0	385.9
Accident reduction as % of wet-road accidents	11.6	36.3	24.2
Saving in accident costs (present value)	£426,000	£1,381,000	£1,807,000
Net annual economic return (%)	214.6	40.1	50.4
Cost of preventing one accident	£107	£519	£422